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WATER MOTORS.

A Lecture by PROFESSOR W. C. UNWIN, B. Sc., M. Inst. C. E.

From the Transactions of the Institution of Civil Engineers.

WHEN the Council did me the honor to ask me to lecture on Hydraulic Motors, I I could not but feel that they imposed on me a task of some difficulty. The lectures of last year on the applications of steam-power related to a matter of pre-eminent national importance, and to one involving some of the most striking and brilliant scientific discoveries of this century. In describing the work of Joule and Rankine and Siemens, the lecturers of last year were recalling names familiar and honored in this Institution, and discoveries which form the most characteristic scientific advance of recent times.

Water motors are not now, or in this country, so important as heat motors, and there is even possibly, among many engineers, an impression that water motors are at best rather feeble machines, suitable only for small industries. Nevertheless, I believe that even now a much larger amount of water-power is utilized than is generally known, and in circumstances not impossible, or even very improbable, the importance of water-power even in this country, might be greatly increased. In some by no means very indefinitely deferred period, there must begin to be felt something of the pressure due to the limitation of the coal supply. No great increase of the price of coal is needed to make water-power much more valuable than it is at present. On the other hand, if the electrical engineer will make the transmission of energy easier, the importance of water-power would also increase, for one of its greatest defects is that it exists in the localities where nature has placed it, and not in the places where it can be most conveniently used.

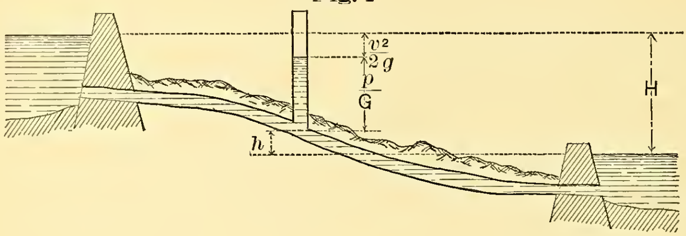
Numerous isolated cases of the transmission of energy electrically, to do mechanical work at a distance, are no doubt already in successful operation, but in most of these cases the installation has been more or less of an experiment, and the cost has not been greatly regarded. But one case, in which the electrical transmission of water-power has been successfully carried out on a strictly commercial basis, has come under my notice. At Bienne, in Switzerland, the power of a Girard turbine is transmitted electrically a distance of 4,000 feet, and used to drive workshops. The dynamos are compound-wound, and the conductors are carried on posts. A diminution in the cost of electrical apparatus would probably render such cases much more numerous.

The term water-power is convenient, but inaccurate. Strictly speaking, there is no such thing as water-power. Whether the water descends on a water wheel, or actuates a pressure-engine in connection with Mr. Ellington's hydraulic pressure-mains, the water is a mere agent of transmission. In one case the water wheel is driven by the energy of gravitation, in the other by the energy developed in a steam-engine; the water merely transmits the pull of gravity or the push of the steam-engine. In neither case is the water itself the source of the power utilized. As we speak of a steam-engine as a heat motor, so we might speak of most water motors as gravity motors.

However, using the term water-power as a convenient one, it may be pointed out that, though a good deal of water-power is already utilized in this country, and though a few motors of very considerable power exist here, it is on the Continent and in America, where coal is dearer, that the most striking instances of the utilization of water-power are to be found. Many members of this Institution have probably seen the turbines at the falls of Schaffhausen, the power of which is distributed to several mills by wire ropes. In the report of the Technical Education Commission there is an interesting account of a visit to Windisch, where 1,000 H.P. are utilized, the weir and turbines having cost £70,000. At Bellegarde, at the confluence of the Rhone and the Valserine, on a fall of 40 feet, 3,700 H.P. are utilized by six turbines, and this amount of power would have been doubled if the project had been commercially successful. Water-power is utilized on a still larger scale in America.

Holyoke and its Water-power.—About 18 miles from the mouth of the Connecticut river there was a fall of about 60 feet in a short distance, forming what were called the Great Rapids, below which the river turned sharply, forming a kind of peninsula, on which the city of Holyoke is now built. In 1831 the first mill was erected and driven by water-power. In 1845, the magnitude of the water-power available attracted attention, and it was decided to build a dam across the river. The ordinary flow of the river is 6,000 cubic feet per second, giving a gross power of thirty thousand horses, or in dry seasons probably not less than twenty thousand horses. In a recent exceptional summer it seems to have fallen, for a time, to half this amount. The first weir or dam was completed in in 1847, but it was carried away. A second dam was built in 1849, with a base of 80 feet and a height of 30 feet. The dam is a timber cribwork filled with stone, and rests on rock. In 1868 it was found necessary to construct an apron to this weir, 50 feet in width. The whole structure is now 130 feet wide, 30 feet above the river bed, and 1,019 feet in length. From above the weir, a system of canals takes the water to the mills on three levels. The first canal starts with a width of 140 feet, and depth of 22 feet. A second canal, parallel through a distance of a mile with the first, takes the water after passing through the mills, and supplies it to a second series of mills. There is also a third canal, at a different level.

Fig. 1



With the grant of land for a mill is also leased the right to use the water-power, and the lease of the water-power is transferred to successive tenants with the lease of the mill. A mill-power is defined as 38 cubic feet of water per second, during 16 hours per day, on a fall of 20 feet. This gives a gross power of eighty-six horses, or an effective power, with a good turbine, of about sixty-three horses. The charge for the power is at the rate of 20s. per horse-power per annum. Mr. Emerson, from whom I borrow my data, may well say that Holyoke affords the cheapest manufacturing power in the world.

There are numerous other cases in America where water-power is supplied in a similar way at a cost varying from £1 to £5 per horse-power per annum. At Bellegarde, I believe, the proposed charge was £8 to £12 per horse-power per annum.

The ordinary source of water-power is a supply of water raised by the sun's heat to a convenient elevation, and falling through natural channels back to the sea. On each pound of water descending H feet, gravity does H foot-pounds of work. We call H the head due to the elevation, meaning by head the energy per pound of water which would be communicated by gravity during its descent, and which is recoverable by suitable machinery.

Suppose the water to descend at a uniform rate through a pipe (Fig. 1), whcih we may imagine frictionless. At any point h feet above the lower level, the water will in general have acquired a pressure p and a velocity v. And in that case we know that

$$H=h+\frac{p}{G}+\frac{v^2}{2g}$$

where h is the unexpended part of the fall, $\frac{p}{G}$ is the energy corresponding to the pressure, and $\frac{v^2}{2g}$ the energy corresponding to the velocity of each pound of water. Consequently, the head may take three different forms, and, at whatever point of the pipe we make the examination, these three portions of head add up to the same total amount.

Corresponding to each of these three forms which the head takes, there is a class of water motors. By a bucket water-wheel we can recover the energy corresponding to an unexpended part of the fall; by a pressure-engine we can get the energy due to the pressure, and by a turbine we can get the energy due to the velocity.

I.—Bucket or Cell Wheels.

First, then, there are bucket or cell wheels, in which the water fills the buckets near the top of the fall and descends in contact with the wheel without acceleration.

About this class of motors I have time to say very little. They are simple in principle, and have a fairly high efficiency. But they are somewhat cumbrous and antiquated machines. On falls above 70 feet they cannot be used. On falls of 20 to 60 feet a turbine is cheaper, and yields an equal efficiency. On a low fall, if a turbine costs as much, it has, if well constructed, a higher efficiency. Still in one respect a good overshot or high-breast wheel is superior to most more modern water motors. Its efficiency is nearly the same with a reduced supply of water as with the full supply. In this respect many turbines, otherwise excellent, compare very unfavorably with the water wheel. It is probably because many turbines are not so good as they might be, and because many are extremely bad, that the water-wheel is still constructed for the falls for which it is most suitable.

II. Pressure Engines.

The second way of utilizing water-power is to bring the water to the level of discharge in a closed pipe at small velocity, but with a pressure but little less than that due to the height of fall. The water under pressure acts on the piston of a pressure-engine precisely as steam acts in a steam-engine. There are numerous hilly mining districts, especially in Germany, where water-pressure engines are used. Hydraulic lifts and hydraulic cranes in connection with accumulators, are pressure-engines driven by an artificially-created head of water.

Now, although a water-pressure engine is, in certain cases, a perfectly successful and economical machine, it is not, in most cases, the best plan to utilize water power in this way. It may, perhaps, be instructive to consider why, almost without exception, we use a cylinder and piston with steam, and yet only exceptionally resort to the same expedient with water.

The great difference between steam under pressure and water under pressure is this—that one is a comparatively light fluid indefinitely expansible, the other a comparatively heavy fluid, the volume of which is not measurably changed by any ordinary variation of pressure.

The frictional losses of energy in a fluid are proportional to its weight. If, for instance, water is 500 times heavier than steam, then at the same velocities of flow the frictional losses are 500 times greater in the water than in the steam.

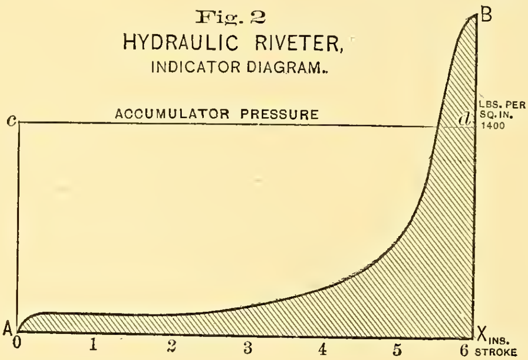
To prevent enormous waste of energy in friction, a water-pressure engine must be run much more slowly than a steam-engine, and all the pipes and passages for a given volume of flow must be much larger. A steam-engine has a piston speed of 400 or 500 feet per minute; a water-pressure engine rarely has a speed exceeding 80 feet per minute. Steam flows in steam-pipes with a velocity of 100 feet per second, but in the passages of a pressure-engine the velocity of the water does not exceed 4 to 6 feet per second. Hence, for a given power a water-pressure engine is much more cumbrous than a steam-engine, except in those cases were the water-pressure is 8 or 10 times as great as is practicable with steam. It is just when an exceptionally high pressure can be obtained, or requires to be used, that the water-pressure engine is most applicable.

The second difficulty in the use of water in a pressure-engine arises out of its incompressibility. The same volume of water, and, consequently, in most cases, the same amount of energy must be expended each stroke, whether the resistance is great or small. If a hydraulic lift rises, the same volume of water is expended whether the lift is empty or loaded. Where the work is intermittent, this disadvantage is often far more than counterbalanced by the other advantages of the use of water. But where the work is continuous, the waste of energy is more serious. Suppose a pressure-engine is employed—as it not uncommonly is—in pumping. Then the pressure cylinder must be so proportioned that the work is done when the fall supplying the pressure is lowest and the lift highest. If the fall increases or the lift diminishes, no economy of water is realizable, but some prejudicial resistance by throttling must be created to prevent the engine running away and to absorb and waste the surplus energy. Such engines only work, with good efficiency, with a constant fall and lift, and only then when quite exactly proportioned to the work to be done.

Many years ago Sir W. Armstrong invented the plan of distributing hydraulic power in towns. For doing intermittent work, especially for lifting purposes, the system of hydraulic-pressure mains has proved altogether successful; the most remarkable application being the system of several miles of mains worked at a pressure of 800 pounds per square inch, and successfully laid in the streets of London by Mr. Ellington. Hitherto, however, the system has not proved so useful for ordinary power purposes, as was no doubt originally expected. The pressure is too great to be conveniently applied in a turbine, and the pressure-engine in its ordinary form is too extravagant in its consumption of water for ordinary power purposes.

It has been proposed to admit a variable quantity of water to the pressure cylinder from the pressure main, and to complete the stroke with water drawn from a low-level reservoir. The driving effort would then be very irregular, but the plan does not seem impossible. Some years ago Mr. Hastie invented a pressure-engine, in which, by very ingenious automatic gear, the stroke of the engine is varied, diminishing when the

Fig. 2
HYDRAULIC RIVETER,
INDICATOR DIAGRAM.



resistance decreases, and increasing when the resistance increases.

Through the kindness of Mr. Ellington, a drawing is exhibited of an improved "Hastie" engine, which is being introduced for power purposes in London. The engine has fixed cylinders, on the plan of the "Brotherhood" engine, and the spring gear which alters the stroke is much simpler than in the original engine.

There are other peculiarities in the action of water-pressure engines, which arise out of the weight and incompressibility of the acting fluid. In the first place, the whole column of water between the pressure cylinder and the supply reservoir virtually forms part of the piston of the engine, so that a water-pressure engine is, in general, an engine with a very heavy piston. The effect of the inertia of the piston is very well understood. It tends to make the effective effort transmitted smaller than the pressure on the piston in the first half of the stroke, and greater than the pressure on the piston in the second half of the stroke. In a steam-engine this is often an advantage. The diminution of steam-pressure, due to expansion, can be in great part neutralized by the effect of the inertia of the piston. At any rate, the inertia of the piston generally tends to diminish the inequality of the driving effort. It is otherwise with a water-pressure engine, in which the water-pressure, being constant, the effect of inertia is to render the driving effort variable; and this is so much the less advantageous, because, while with the light fluid, steam, we can neglect the weight of the fluid, with water we must reckon the weight of water in the supply pipe as forming part of the piston.

I believe that the precise part played by the inertia of the water in the motion of a pressure engine has first been indicated by Professor Cotterill in his "Treatise on Applied Mechanics." He has specially treated of the case of a rotating engine, while I shall consider rather those pressure-engines which make a stroke, uncontrolled by a crank and fly-wheel. In such engines the inertia of the fluid behind the piston tends to produce an acceleration of velocity and shock at the end of the stroke, which, in general, can only be prevented by means which reduce the efficiency of the engine.

In a very early water-pressure engine of Trevitheck's the piston valve was made less in length than the width of the port, so that for a short period the supply pipe was directly open to the exhaust, the flow being gradually arrested by wire-drawing as the valve closed. This involves very great waste. In later engines the valve closes somewhat gradually toward the end of the stroke, so as to retard the flow. But the resistance thus created absorbs and wastes most of the kinetic energy of the water in the supply pipe.

We diminish the difficulty due to the inertia of the moving mass of water by very much restricting its velocity. It is mainly on account of the inertia of the water that, while steam-engines are run at 400 to 600 feet of piston-speed per second, water-pressure engines are rarely run at more than 60 to 80 feet per minute.

There are certain cases in which the friction and inertia of the fluid, which in most cases are prejudicial, render essential service in the working of the machine. The friction increasing as the square of the velocity acts as a brake in preventing the velocity from becoming excessive, and the diminution of the effective effort at the beginning of the stroke, and its increase at the end of the stroke, which is due to the inertia of the fluid column, is extremely advantageous in certain operations.

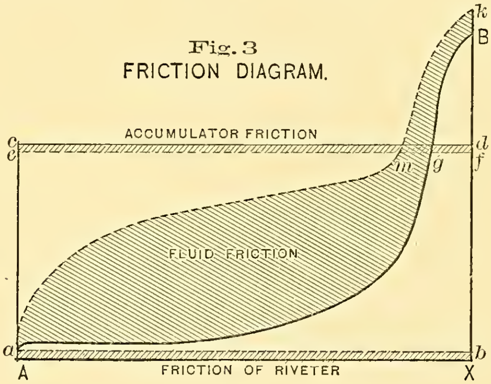
All members of this Institution will be acquainted with Mr. Tweddell's admirable hydraulic riveting and punching machinery. It is well known that those machines work not only very efficiently in the sense of doing their work well, but they work with a smaller expenditure of power than machines driven by gearing. That is due partly to saving the friction of the gearing, but mainly to the fact that the machines make no waste strokes. They do not keep on running while waiting for work. On the other hand, in the actual working stroke there is a proportionately large loss of work.

Fig. 2 shows a diagram from a riveter driven by a differential accumulator through 30 feet of 1-inch pipe. The water in the pipe accelerates and is retarded proportionately to the movement of the riveter ram, and the accumulator weight also accelerates and retards in the same way. Hence, the water in the pipe and the accumulator weight virtually form part of the moving riveter ram. But as the accumulator weight moves six times as fast as the riveter ram, the forces due to its inertia are thirty-six times as great as if it were attached to and moved with the riveter ram; and as the water moves eighty-one times as fast as the ram, the forces due to its inertia are more than six thousand times as great as if the water moved at the same speed as the ram. In this machine, therefore, the virtual weight of the ram which closes the rivet, and which is put in motion and stopped every stroke is 300 tons.

To control the movement of such a mass as this, powerful brake-action is necessary, and Mr. Tweddell's brake is supplied by the automatic action of the water-friction.

On looking at the diagram, Fig. 2, it will be seen that the effect of the inertia is to greatly diminish the pressure in the beginning of the stroke, and to increase it above the accumulator pressure at the end of the stroke. That is advantageous in closing the rivet. But a large part of the diagram is missing; apart from friction and inertia, the diagram would be a rectangle A*cd*X. The actual pressure line falls greatly below this. Fig. 3 shows an estimate of the friction. There are two rectangles, A*ab*X and *ecdf*, showing the uniform friction of the cup leathers of the riveter and accumulator rams, and there is a surprisingly large area, *amk*B*g*, representing the friction of the water in the 1-inch pipe. In fact, it is this friction which determines the speed of the machine, and keeps it down to the safe limit of 1 foot per second at most. When the friction diagram is added to the diagram of useful work, we see that the unbalanced or stored work in the first half of the stroke *aem* is nearly equal to the excess of work, *mkf* at the end of the stroke, so that the machine comes to rest without any violent shock. Mr. Tweddell's riveter is virtually a 300-ton hammer, controlled by a powerful automatic friction brake. Fig. 4 shows better the work stored in the first part of the stroke and re-stored in the second.

Fig. 3
FRICTION DIAGRAM.



III. Turbines.

There are motors, of which the undershot wheel is an old type and the turbine a modern type, in which the head is allowed to take the third form before acting on the motor. On undershot wheels and turbines the water acts in virtue of its velocity. Let the water acquire a velocity due to the head in a given direction. Then the water, by its inertia, opposes change of velocity and direction. In the class of wheels now discussed, the water gives up its energy through this action of its inertia. We have now to study under what conditions we can best recover the energy of motion of the water.

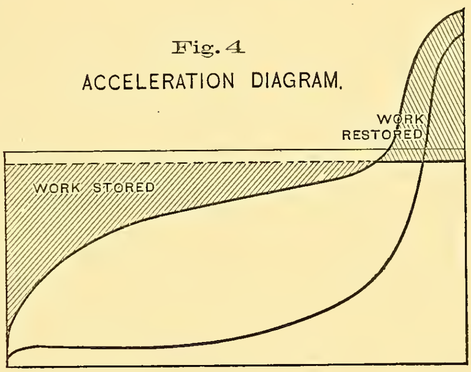
Of the whole energy expended by the water on the machine, a part is taken up and utilized, another part is wasted or lost. It is the object of the designer to make the latter part as small as possible, and it is therefore necessary to consider in what ways this loss or waste of energy may arise.

1st. There is a waste of energy if the water is allowed to break up into eddies or irregular motions. When water breaks up in this way we say there is loss by shock.

2d. The water leaving the machine may carry off with it part of its energy, there is then a waste of unutilized energy. In many motors this loss is a large one. In the class of motors now considered, this energy rejected can be made as small an amount as we please.

3d. In flowing over the solid surfaces of the machine there is what is termed fluid or skin friction. This is really a loss of the same kind as that due to shock, because skin friction arises from the production of small eddies against the roughnesses of the solid surfaces, or from instability in the fluid itself.

Fig. 4
ACCELERATION DIAGRAM.



There are some smaller losses due to leakage, friction of bearings, and so on, which, for the purpose of this lecture, may be treated as negligible.

Losses due to shock or breaking-up.—If water is poured from a height into a basin, it acquires, in falling, energy of motion. Reaching the vessel, it is dashed about in different directions and broken up into eddying masses. In a short time the friction destroys this irregular motion, and the energy is wasted.

There is generally such a breaking-up of the fluid and waste of energy if the direction of motion or velocity of a fluid stream is abruptly changed.

Let the water be moving along a pipe which changes section abruptly. Then the velocity v_1 in the first part is changed to v_2 in the second. At the abrupt change of section, eddies are continually formed, which carry off part of the energy of the fluid in a useless form. The energy thus subtracted from the energy of translation, and for practical purposes lost, is—

$$\frac{(v_1 - v_2)^2}{2g}$$

For example, if the section of the pipe is doubled, the loss of energy is one-fourth.

So much for abrupt change of velocity. Next, consider abrupt change of direction. To make the problem quite simple, suppose the water flowing round a bent trough ABCD, Fig. 5. At each bend eddies will be formed at the expense of the energy of flow along the surface. Resolve v_1 at A into a component v_2 parallel to AB and a normal component u_1. Then the energy corresponding to u_1 is wasted, and the water proceeds along AB with the velocity v_2. Resolve v_2 at B into a component v_3 parallel to BC, and a normal component u_2. Then u_2 is wasted. Thus, for the whole surface, there is wasted for each pound of water—

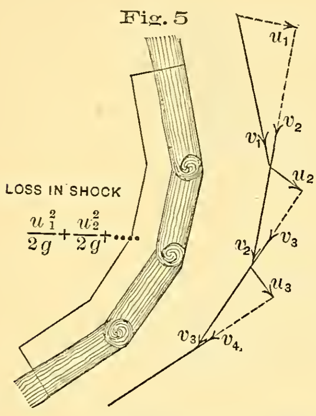
$$\frac{u_1^2}{2g} + \frac{u_2^2}{2g} + \frac{u_3^2}{2g} + \ldots\ldots$$

Now notice the velocities u_1, u_2, u_3, depend on the angles at the bends, and vanish if those angles are indefinitely small. Hence, if the surface is curved throughout, there is no loss due to breaking-up, and the water flows round with its velocity unchanged, except so far as there may be a very small loss, due to the friction of the surface.

Hence the second condition for avoiding loss in dealing with streams of water is, that the surfaces over which it flows should be gradually and regularly curved.

Generally in hydraulic motors we have to deal with fixed jets of water impinging on moving curved vanes. The condition of avoiding loss due to abrupt change of direction imposes a third very important condition as to the direction of the vane where the jet first impinges. Let AB be the fixed jet of water, BC the moving vane. Let v_2 be the velocity of the jet, and u the velocity of the vane. Resolve v_2 into a component u equal and parallel to the velocity of the vane, and a relative component v_r. Then, if the tangent to the vane at B is parallel to v_r, there is no change of direction when the water first

Fig. 5



impinges on the vane, and no loss due to eddies or breaking-up.

These three conditions—gradual change of section, gradual change of the curvature of the surfaces, and the inclination of the receiving edge of the vanes in the direction of relative motion—can always be satisfied, and hence there need be no loss in an hydraulic motor, due to the shock or breaking up of the fluid.

The two other sources of loss in an hydraulic motor, the energy carried away, and the skin friction against the surfaces of the motor are not so easily disposed of. We can, indeed, reduce the energy carried away almost as much as we please. If there were no skin friction, turbines might have any efficiency short of 100 per cent. The energy carried away in good turbines is often not more than 6 per cent. But it might be reduced to 3 per cent. or 1 per cent., only in doing this, we should in general, seriously increase the loss from skin friction.

It is this loss from skin friction which regulates the proportions of turbines, and which compels us to use, in many cases, small and high-speed turbines on high falls. The writer erected a 70-H. P. turbine on 250 feet fall, with a wheel, 15 inches in diameter, making 1500 revolutions per minute. The skin friction of the disks of this turbine probably amounted to 4 horse-power. If the diameter had been doubled to reduce the speed to 750 revolutions, the skin friction would probably have amounted to 16 horse-power.

Before considering the more complex case of turbines, it will be convenient to examine one or two simpler cases in which these principles are applied.

Consider first, the old form of undershot water-wheel. The water issuing under a sluice with nearly the whole velocity due to the head, strikes the radial floats. There is a loss due to breaking-up, and as the water flowing away cannot have a less velocity than the wheel, there is a large amount of energy rejected. Under the best conditions when the wheel has half the velocity due to the fall, 25 per cent. is lost by shock, and 25 per cent. rejected into the tail race. So that apart from the losses by friction and leakage, an undershot wheel utilizes less than half the energy of the fall.

Many years ago General Poncelet recognized the causes of loss in the ordinary undershot wheel, and constructed the well-known Poncelet wheel. I pass over this to examine another less known example of a wheel of this type.

If a jet strikes a hollow cup, larger than itself, there is little loss due to breaking-up, the jet spreading symmetrically. The water spreads with the relative velocity $V-v$, which is reversed in direction at the lip and become $-(V-v)$, so that the absolute velocity of discharge is $-(V-v)+v=2v-V$. By making $v=\frac{1}{2}V$, the water leaves the cup with no energy left, that is, all the energy of the jet is expended on the cup.

Now, to supply the placer mines in California, canals or "ditches" have been built high on the slopes of the Sierra Nevada. These deliver water at an elevation of 1,000 to 3,000 feet above the great valley of California. In many cases the mines have been exhausted or abandoned, and hence, has arisen the idea of using the water-power, amounting in the aggregate to several hundred thousand horse-power for mills or quartz crushing.

The fall is here excessively great, and if it were attempted to use turbines, especially those forms most in favor in America, there would be the inconvenience that the turbines would run at an immoderate, and in some cases, an unmanageably great speed. This has the double disadvantage of involving great wear and tear, and of requiring a large amount of gearing, with its concomitant frictional waste.

About twenty years ago there was introduced, a form of impact wheel, which, with American talent for nicknames, was called the Hurdy-Gurdy. It consisted of a wheel of considerable diameter, with a series of cast-iron floats, 4 to 6 inches wide on the face. A jet of water of very small diameter (three-eighths of an inch sometimes) was allowed to strike the vanes normally. Theory shows that in this case the wheel should run at half the speed of the jet, and that the efficiency, even apart from friction, could not exceed 50 per cent. Practical experience also showed that the wheel should have half the velocity of the jet, and the efficiency was found, by experiment, to be 40 per cent. In spite of the low efficiency, such wheels seem to have been useful, partly, because they were cheap and free from liability to accident, but mainly, probably, because by choice of diameter of wheel, any convenient speed of rotation can be obtained.

It is easy to see that the efficiency could be improved by substituting cups for flat floats, and this is what has actually been done. The favorite wheel now is a wheel termed the Pelton wheel, the floats of which are simply cups which deviate the water backwards. A wheel of this kind, working to 107 horse-power, under a head of 386 feet, is said to have given an efficiency of 87 per cent. Without accepting exactly this figure, I see no reason why, with a very high fall, an efficiency of 80 per cent. at all events, should not be reached.

At the Idaho mines, seven of these Pelton wheels have recently been erected to work to about 320 horse-power, driving machinery previously driven by steam. The water is brought a distance of 9,000 feet, in a thin wrought-iron riveted main, 22 inches in diameter. The total head is 542.6 feet, reduced by friction in the main to an effective head of 523 feet. The nozzles by which the water is delivered to the wheels are from $\frac{15}{16}$ to $1\frac{15}{16}$ inch in diameter, and the power is taken from the wheels by 2-inch manila ropes in grooved pulleys, the cost of the change from steam to water-power was between £10,000 and £11,000. The wheels work with hardly any attention or wear, and are believed to give 80 per cent.

The Jet Reaction Wheel or Scotch Turbine.

There is a very simple form of reaction wheel, which forms a convenient step towards a true turbine. In this the water enters the center of the wheel, spreads radially, and issues in jets tangentially to the direction of revolution. The water issues under the head h due to the fall and $\frac{v^2}{2g}$ due to the centrifugal force of the mass of water in the wheel. Let V be the velocity of the wheel, then the velocity of the water through the orifices is

$$v=\sqrt{2gh+V^2}$$

and the backward velocity of the water at the jets is

$$v-V=\sqrt{2gh+V^2}-V$$

It is obvious that this approaches zero as V approaches infinity. For any smaller speed, part of the energy of the fall is rejected into the tail race in the backward motion of the water. Taking friction into account, the best speed of the wheel is the velocity due to the head, and then about 17 per cent. of the energy is carried away, and another 10 or 15 per cent. is lost in friction.

Now, it was the study of the source of the waste of energy in this wheel which led Fourneyron to the invention of the turbine. Fourneyron perceived that in order to avoid the loss due to the backward velocity of discharge, an initial forward velocity must be given to the water. By putting the water in rotation forwards by fixed guide-blades before it enters the revolving wheel, the backward velocity of discharge can be made as small as we please, and then the efficiency of the turbine may approach 100 per cent. as nearly as we please, apart from the frictional losses, which can in no case be prevented.

The Scotch turbine would, from its simplicity, be still used in certain cases, but for two serious practical defects. One is, that it is the most unstable in speed of all turbines; the other is, that it admits of no efficient mode of regulation for a variation of water-supply.

At the beginning of this century there existed a number of horizontally rotating water-wheels, driven by jets of water or by rotating masses of water, which acted on them chiefly by their inertia. The efficiency of these was very low. In some treatises, especially those of Euler, there were indications of the true principles of construction of such a motor. But it was M. Fourneyron, in 1827, who first realized a practical turbine. M. Fourneyron received the prize of 6,000f. for his invention from the Société d'Encouragement. His turbine is still sometimes constructed with very little modification, and its essential features are present in turbines of all constructions.

M. Fourneyron perceived that if the water was to leave the wheel without any backward velocity, that is, without carrying away and wasting energy, the water must have given it some initial forward velocity before entering the wheel, and his invention mainly consisted in the introduction of guide-blades to give that initial forward velocity.

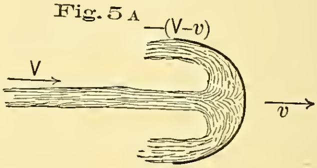
In the Fourneyron turbine, the water descending into the center of the wheel is put into rotation by the guide-blades, and passes into the wheel with a velocity rather less than that due to the head. It passes through the wheel radially and outwards, and hence the Fourneyron turbine is called an outward-flow turbine. The great defect of the Fourneyron turbine is the practical difficulty of constructing any good form of sluice for regulating the power of the turbine. With the cylindrical sluice ordinarily used between the guide-blades and wheel, the efficiency falls off rapidly as the supply of water is diminished; and it is this practical difficulty which I think is leading to a general abandonment of the Fourneyron turbine.

The Fourneyron turbine was soon succeeded by the Jonval turbine, in which the water flows parallel to the axis of the turbine. The Fourneyron turbine works best above the tail water. The Jonval turbine has the advantage that it can be placed below the tail water, or at any height less than thirty feet above it with a suction pipe. But its sluice arrangements are even worse than those of the Fourneyron turbine.

Lastly, Professor James Thomson introduced an inward-flow turbine, in which the water flows radially inwards and is discharged at the center of the wheel. The greatest advantage of this arrangement is that a perfect system of movable sluices or guide-blades can be adopted to regulate the power of the turbine, there being ample space to arrange these outside the wheel.

There are, therefore, outward flow, in-

Fig. 5 A



ward flow, and axial or parallel flow turbines. To these must be added a form used by the late Mr. Schiele, in which the water flows inwards radially and afterwards axially, the wheel vanes being prolonged nearly to the center of the wheel, and which may be called a mixed-flow turbine.

Now, in all these turbines, and in all modifications of them constructed for many years, a peculiarity of proportion originally adopted by M. Fourneyron was followed. Instead of allowing the water to issue from the guide-blades with the whole velocity due to the head, he so proportioned the passages that there was a more or less considerable pressure in the space between the guide-blades and wheel. All these turbines are therefore pressure turbines—that is, turbines in which the water enters the wheel under pressure.

To maintain this pressure properly two conditions are necessary—the wheel passages must be completely filled with the stream of entering water, and consequently the wheel must receive the water continuously over the whole circumference simultaneously. These are therefore turbines with complete admission.

M. Girard was the first to perceive

clearly the advantage of departing from Fourneyron's practice. M. Girard constructed turbines in which the water issued from the guide-blades with the full velocity due to the fall, and therefore with no pressure. The wheel must be placed entirely out of the tail water, so that the issuing water is freely deviated on the curved vanes of the wheel. Nearly the whole energy of motion of the water, less the loss in friction, is given up to the wheel. Turbines of this kind are called turbines of free deviation or impulse turbines.

Impulse turbines may be inward, outward, or parallel flow turbines, but they are very commonly outward flow. For normal conditions of working they are slightly less satisfactory than pressure turbines, but they have two very great practical advantages.

In a pressure turbine there must be a definite rate of flow through the wheel to maintain the exact distribution of pressure in the wheel for which it is calculated. If the guide-blade passages are partially closed, the distribution of the hydraulic pressure is completely altered, and the efficiency reduced. In the turbine of free deviation, on the other hand, there is no possible change of pressure in the wheel, for it is all open to the air. Each particle of water following the curve of the wheel-vane acts by itself alone without any interference from its neighbors. Hence, if the guide passages are partially closed, the stream on the wheel is rendered thinner, but its efficiency is in no way impaired. Hence the regulation of the Girard turbine is in general far more perfect than in a pressure turbine.

Classification of Turbines.

I.—*Impulse Turbines.*

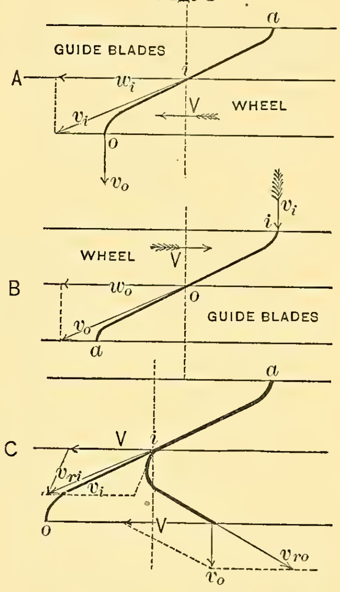
Wheel passages not filled.
Free deviation.
No pressure between guide passages and wheel.
Discharge above tail water.
a. Complete admission.
b. Partial admission.
Axial, inward or outward flow.

II.—*Pressure or Reaction Turbines.*

Wheel passages filled.
Pressure between guide-blades and wheel.
Discharge above tail-water (outward flow); or below tail-water (parallel or inward flow); or into suction pipes (parallel or inward flow).
Always complete admission, axial, inward, outward, or mixed (inward and downward) flow.

To simplify the consideration of the action of the water in a turbine, suppose that for a turbine wheel moving circularly

Fig. 6



we substitute a turbine rod moving in a straight line.* We can pass to the case of the wheel easily afterwards. To be definite, suppose the water flowing vertically downwards, and the rod (Fig. 6, A) moving horizontally from right. to left. To give the initial necessary forward velocity the water must be deflected in some path *a i* by fixed guide-blades. Entering the wheel, it produces pressure due to deviation by the wheel vanes, and traverses a path, *i o*, leaving the wheel finally with a much reduced velocity in a direction normal to the surface of discharge.

A simple application of Newton's second law of motion gives at once the force driving the wheel. The water enters the

* The development of a section of an axial flow turbine has always been treated in this way, but the use of a turbine rod as the first step in designing any turbine is due to Von Reiche.

wheel with the initial velocity v_i, which has the horizontal component w_i, and leaves the wheel with a velocity which has no horizontal component. Each pound of water per second, therefore, loses the horizontal momentum $\frac{w_i}{g}$, and since impulse is equal to change of momentum, the horizontal pressure on the wheel is

$$\frac{w_i}{g} \text{ lbs.}$$

for each pound per second flowing through the wheel, and the useful work done in driving the wheel is

In applying this formula, the fall H is the effective fall—that is, the fall after deducting any losses in the supply-pipe tail-race, etc., which are extraneous to the turbine. From the work ηH really utilized by the turbine, an additional small loss occurs in the transmission, from friction of the shaft, friction on the wheel-covers and friction of gearing.

It is now to be seen what forms the guide-blades and wheel-vanes must have to direct the water in the absolute path chosen for it.

The guide-blades, being fixed, have exactly the form of the chosen water-paths *a i*, Fig. 6, A, or *o a*, Fig. 6, B. But the

Fig. 7

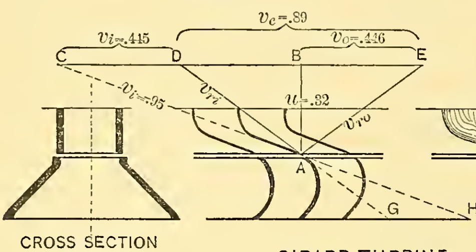
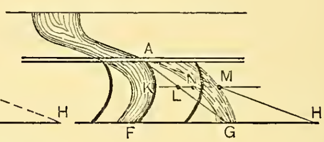


Fig. 8



GIRARD TURBINE

h=29.5;
$\sqrt{2gh}$=43.6;
η=0.89²=0.79.

$$\frac{w_i V}{g} \text{ foot-lbs. per second.}$$

But the whole energy of gravity on each pound of water falling H feet is H foot-pounds. Hence, if η is the efficiency,

$$\eta H = \frac{W_i V}{g}.$$

This is the fundamental equation on which the whole design of turbines depends. It gives the relation between the original whirling velocity of the water and the velocity of the wheel.

I stop for a moment to point out that exactly the same result is arrived at if the position of the wheel and guide-blades is inverted as in Fig. 6, B. Then the water having no initial forward momentum gains the momentum $\frac{w_o}{g}$ in the wheel, and the equation becomes

$$\eta H = \frac{w_o V}{g}.$$

wheel-vanes have a quite different form from the water-path, because as water moves along that path the wheel also is moving.

In order that the water may enter the wheel without shock, the first element of the vane must be parallel to v_{ri}, Fig. 6, C, the direction of relative motion. In order that the final velocity of the water may be vertical, the last element of the wheel-vane must be parallel to v_{ro}, obtained by compounding the final velocity v_o with the velocity V of the wheel. Having obtained the tangents to the two ends of the wheel-vane, any smooth curve joining these two will satisfy the necessary conditions for the proper action of the water.

Turbine Rod Corresponding to a Girard or Impulse Turbine.

In the Girard turbine there is no pressure in the clearance space, and therefore the water issues from the guide-blades with the velocity due to the effective fall. In the diagram

$$v_i = 0.95\sqrt{2gH}$$

which allows for the friction of the guide-blades.

Next decide what energy shall be rejected into the tail-race. Suppose this is put at 10 per cent., the velocity corresponding to one-tenth of the fall is

$$u = 0.32\sqrt{2gH}.$$

Draw now the triangle of velocities CAB, so that u is the vertical component of v_i. Then CA is the direction in which the water enters the wheel.*

Bisect CB in D. Then CD is the proper velocity of the wheel, and AD is the direction of relative motion of the water and wheel, and tangent to the first element of the wheel-vanes.

In an impulse turbine the relative velocity remains unchanged. Set off BE = the velocity of the wheel, then AE, which obviously by construction is equal to DA, is the direction of relative motion of the water leaving the wheel, and the tangent to the last element of the wheel-vanes.

We have now determined all three angles necessary for drawing the guide-blades and wheel-vanes.

Further, since the relative velocity v_{ri} is changed to v_{ro} in passing through the wheel, therefore DE or V_e is the velocity utilized in the wheel. Hence the work utilized is

$$\frac{V_e^2}{2g},$$

and the efficiency of the wheel is $0.89^2 = 0.79$, apart from those losses which are extraneous to the turbine itself.

To secure the free deviation of the water on the wheel-vanes, and to prevent the choking of the wheel-passages, it is usual to flare out the wheel, as shown in the cross-section. Very commonly the ratio of the inlet and outlet widths is as 4 to 7.

Every datum for the turbine which depends on hydraulic considerations has therefore been determined. And anyone who has mastered this very simple diagram, and who has the requisite general mechanical knowledge, can design a turbine, I need not say as well as I could, but as well as M. Girard himself could.

In drawing the stream of water on the vane it is merely necessary to remember that the relative velocity is constant, and therefore the thickness of the water-sheet is inversely as the width of the bucket.

It is useful to examine the exact absolute path of the water in the wheel, which is easily obtained. If there were no wheel-vanes the water would traverse the absolute path AH and the relative path AG. But the wheel-vanes deviate the water the distance LK from AG. Set-off MN = LK, then N is a point in the absolute path. Any number of such points can be found and the absolute path drawn. Or conversely, if the absolute path is chosen the wheel-vane can be drawn. The wheel-vanes will be of good form if the absolute path shows a continuous and tolerably uniform curvature, and if the water stream through the wheel is a converging rather than a diverging one.

Turbine Rod Corresponding to a Pressure Turbine.

In a pressure turbine the wheel passages are always full. Hence the velocity of flow, that is, the vertical component of the waters' velocity in the diagram is constant, or at all events is determinable from the general dimensions of the wheel. That velocity is, therefore, the velocity at which the water is rejected into the tail-race. This ought to be small; it is very often only $\frac{1}{8}\sqrt{2gH}$, but to make the diagram clearer, I have taken it at $0.27\sqrt{2gH}$, in which case 7 per cent. of the energy is rejected.

Further, 8 to 15 per cent. of the energy is wasted in friction. Taking the extreme case—suppose 15 per cent. wasted in friction; then there remains 78 per cent. to be utilized in the turbine, and the velocity due to 78 per cent. of the head is 0.88 of the velocity due to the head.

In a pressure turbine this 78 per cent. of the energy is partly used in producing the initial horizontal velocity, and partly in producing the pressure in the clearance space. It is optional how this division is made. In the figure the velocity 0.88 is divided into a horizontal com-

* It is assumed here that the velocity of flow through the wheel, u, is constant. If it is not so, the figure must be drawn with the actual values.

ponent $w_i = 0.66$, and a vertical component $v_p = 0.589$. Hence, if the initial horizontal velocity is taken at $0.66 \sqrt{2gH}$, the velocity corresponding to the pressure in the clearance space will be $0.589 \sqrt{2gH}$.

Setting off the assumed vertical velocity 0.27, and the just found horizontal velocity 0.66, we get the initial velocity and direction of motion of the water $v_i = 0.71 \sqrt{2gH}$, and determine the angle γ of the guide blades.

To determine the proper velocity of the wheel, I shall apply the principle of momentum. As the water enters the wheel

which gives

$$V = 0.78 \frac{gH}{w} = 0.78 \frac{gH}{0.66 \sqrt{2gH}}$$

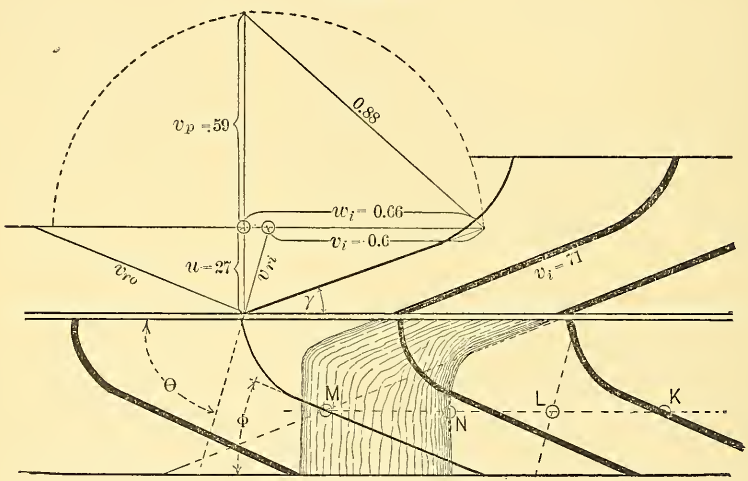
$$V = 0.6 \sqrt{2gH}$$

Knowing V and v_i, we have now the direction of relative motion where the water enters the wheel, and the angle θ of the first element of the wheel-vanes.

Similarly combining u and V, we get the relative velocity v_{ro} at the point of discharge, and the angle φ at the other end of the wheel-vanes.

It is easy to show that the utilized

Fig. 9.



JONVAL

with the horizontal velocity $w_i = 0.66 \sqrt{2gH}$, and leaves with no horizontal momentum, the effective horizontal pressure of each pound of water on the wheel is

$$\frac{w_i}{g} \text{lbs.}$$

and if V is the velocity of the wheel, the useful work done is

$$\frac{w_i V}{g} \text{ ft.-lbs. per pound of water.}$$

But 78 per cent. of the energy due to the head is utilized so that

$$\frac{w_i V}{g} = 0.78 \text{ H},$$

velocity 0.88 is the chord of a semi-circle, of which the velocity V of the wheel is the radius, so that the velocity of the wheel is easily found graphically and without calculation.

Transformation of the Turbine Rod into an Inward or Outward Flow Turbine.—It is not difficult to proceed by methods similar to those already described to draw directly the path and the curves of the vanes of a radial flow turbine. But the proceeding is complicated by the circular motion, and a more simple method is available. If we draw a turbine rod for any given case first, the corresponding inward or outward flow turbine can be obtained by simple geometrical projection.

Draw circles at the same distances

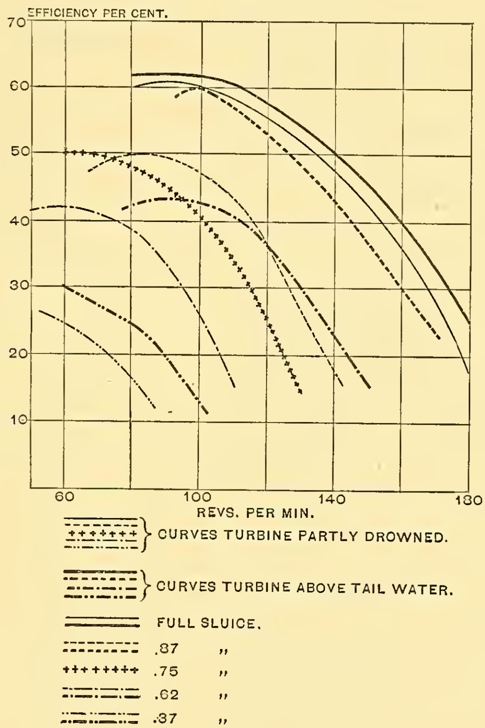
apart as the edges of the guide-blades and wheel in the turbine rod. Subdivide the spaces of the turbine rod by lines at equal distances, and the spaces of the turbine by corresponding equidistant circles. Thus let the circle *b* correspond to the line *b* in the turbine rod. Project the point where *b* intersects the wheel-vane to the circle *a*, and draw a radius. Where this intersects the circle *b* is the corresponding point on the wheel-vane curve. The guide-blade and absolute water-path are projected in the same way.

Efficiency of Turbines.—The largest waste of energy in turbines is due to fluid friction, and this cannot be estimated with any great accuracy, and can only therefore be determined by experiment. There are a number of experiments, too carefully carried out and too accordant to be put aside, which show that turbines of very different types, well constructed, and working in the best conditions, yield an efficiency little, if at all, inferior to 80 per cent. A very few experiments, apparently also reliable, show an efficiency slightly greater. But allowing for the probabilities of error in water measurement, I think that 80 per cent. may be taken as the maximum efficiency of the best turbines in normal conditions of working.

While I do not believe that this efficiency is likely in any case to be exceeded, I believe also that any one of the ordinary types of turbine will, within a very small range of difference, yield the same efficiency. The search of inventors, especially in America, for some new modification of the turbine, which shall have a greater maximum efficiency, I believe to be altogether a chase of the philosopher's stone, and not likely to end more successfully than that of the Rosicrucians.

The statements that this turbine or that has attained 82 or 83 or 85 per cent. of efficiency are not only delusive, they are extremely misleading. The probability is that the small extra percentage of maximum efficiency claimed over that

Fig.10

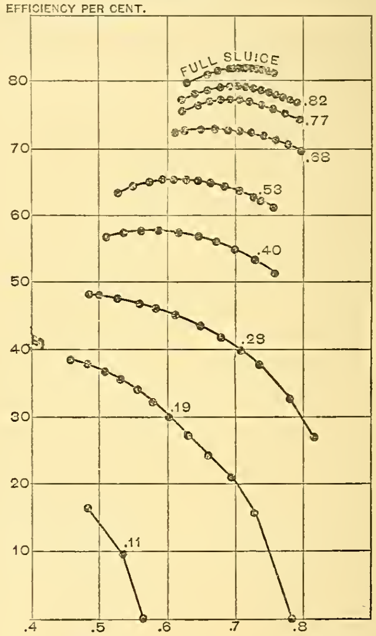


of other turbines is due to error of water measurement. But even if this is not the case, the real practical value of a turbine is not measured by its maximum efficiency when everything has been arranged to suit it, but by the average efficiency in the varying conditions of fall, water-supply, speed, and work to be done, in which it has actually to operate. Now, there is one condition, at all events, which in most turbines is constantly varying. The supply of water varies either from actual deficiency in the supply, or because the work to be done varies. In either case the quantity of water discharged through the turbine varies. To effect this alteration of discharge, turbines are provided with sluices or regulating apparatus. In nearly all cases the use of the regulating apparatus seriously diminishes the efficiency of the turbine, so that the average efficiency is very much lower than the maximum efficiency. In the mode of regulating different turbines, there are differences far more important than any difference of type or mode of action. Before discussing the efficiency of turbines under regulation, there is a preliminary point to clear up.

Some eighteen years ago I plotted the curves shown in Fig. 10, giving the efficiency of a Fourneyron turbine, with different sluice openings and at different speeds. There are two sets of experiments, shown by darker and thinner lines, corresponding to the normal condition for a Fourneyron out of water, and to the case where the turbine was partly drowned. Roughly, the greatest efficiency, when the turbine was not drowned, was 62 per cent. with full sluice, 60 per cent. with seven-eighth sluice, 43 per cent. with five-eighth sluice, and only 30 per cent. with three-eighth sluice. With the turbine drowned the efficiencies were lower.

For each set of experiments the efficiency is greatest for a given speed of the turbine. But, unfortunately, the speed of greatest efficiency is not the same for different openings of the sluice. With full sluice the efficiency is greatest at about one hundred revolutions. But with three-eighth sluice the efficiency is greatest at sixty revolutions or less. Now, generally the speed of a turbine depends on the work to be done, and cannot be adjusted to suit hydraulic requirements. If the speed has to vary, as in pumping, with the demand for water, the speed will very commonly differ from that which suits the turbine best, and the efficiency will not, on the average, reach the maximum value. Still more commonly, a turbine has to drive machinery at a very nearly constant speed. Naturally we choose for that speed the speed of greatest efficiency with full sluice. But then, for that speed, the efficiency falls

Fig.11



Speed in fraction of $\sqrt{2gh}$.

off much more rapidly with the closing of the sluice than I stated before.

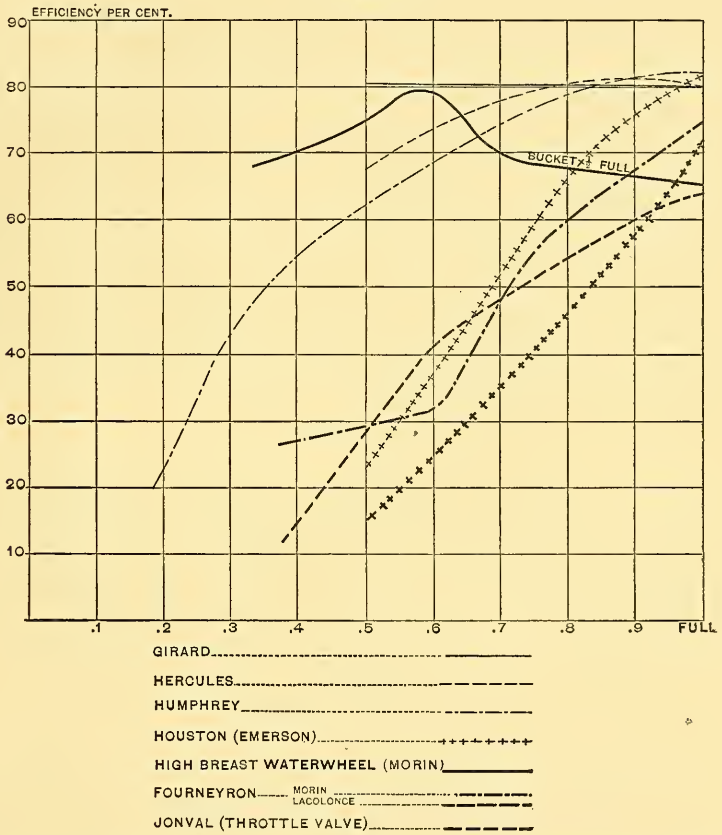
Fig. 11 shows the results of a very extensive series of experiments on the Humphrey turbine, carried out by Mr. Francis at Lowell. The turbine is of 275 horse-power, on 13 feet fall. The experiments were independent of the manufacturers, and the arrangements for water measurement and power measurement were as good as possible. They show the rapid falling off of the efficiency as the sluice closes, and the diminution, at the same time, of the speed of greatest efficiency. The fraction of sluice open is printed against each curve.

Fig. 12 shows the efficiency of different types of turbine for different openings of the sluice, and always for the speed of greatest difficulty with full sluice, and is intended to indicate the importance of adopting a good method of regulation.

The worst mode of regulation of all, though it is still frequently used, is to put a throttle valve in the supply pipe.

The curves for the Hercules and Humphrey turbine show results, I believe, as good as any reliable results obtained in America, the latter being, perhaps, the most reliable, because the experiment was made by Mr. Francis, whose experience in measuring water by weirs is probably greater than that of any other engineer.

Fig. 12



A throttle valve acts entirely by creating a prejudicial resistance, or by destroying part of the effective head.

Next worst to this, perhaps, is the form of sluice adopted in the Fourneyron turbine, a circular cylinder which slides in the clearance space. It is obvious that, when the stream entering the wheel is narrower than the width of the wheel, there must be a general breaking up of the stream, and a complete alteration of the conditions of pressure and velocity for which the wheel curves are designed.

The sluice arrangements in American turbines do not seem, from the theoretical point of view, particularly good; but although American makers do not explain the principles on which they proceed, I suspect that in these turbines some approach is made towards the condition of free deviation, in which case the defects of the sluice produce a less unfavorable effect.

For pressure turbines, only one approximately perfect mode of regulation has ever been adopted, and that is the movable guide-blades of Professor James Thomson. With this arrangement the water enters the wheel over its whole circumference and depth, with its velocity and direction little changed, in all positions of the guide-blades. The only objection to this mode of regulation is that it involves a certain amount of mechanical complication.

For Girard turbines with partial admission, the mode of regulation is simple, and perfectly complies with theoretical conditions ; the width of the stream entering the wheel is altered without in any way affecting the perfect action of the water in the wheel.

On Prince Bismarck's estate at Varzin, three considerable factories worked by turbines have been erected. In the first, in which considerations of capital expenditure were the ruling ones, the turbines were guaranteed to give only 60 per cent. ; in the second, 70 per cent. ; and in the third, to which I am now referring, the turbines were guaranteed by the makers to give 75 per cent. with full sluice and 70 per cent. with half sluice. If this guarantee was not satisfied, the turbines were to be removed without recompense by the makers. These turbines were Girard turbines, and to ascertain whether the conditions of the contract were satisfied, an extremely careful series of experiments were made, the supervision of which was confided to Professor Zeuner, one of the most distinguished professors of mechanical science in Europe. There are two turbines, each of about 200 horse-power, on about 12 feet fall. The general result of the experiments was that the efficiency of the turbines was 0.795 with full sluice, and 0.801 with the sluices half closed, and with the same turbine speed in both cases. These results are the means of four trials in each case, which varied extremely little from one another.

The most careful estimateof the separate losses of work in a turbine which I have met with is that made by Mr. Lehmann. He has analyzed experiments on thirty-six turbines, varying from 1 to 500 horse-power, and has estimated the average losses of energy from various causes as follows :

Loss per cent. due to.......	Axial flow. Turbine.	Outward flow. Turbine.	Inward flow. Turbine.
Hydraulic resistances.......	12	14	10
Unutilized energy..........	3	7	6
Shaft friction.............	3	2	2
Total..................	18	23	18
Efficiency.............	0.82	0.77	0.82

I shall be told—especially by users of turbines in this country—that there are numerous cases of failures of turbines ; of turbines which are not giving satisfaction, or which, if they are doing their work, are using an extravagantly large amount of water. There is, no doubt ground for these complaints ; but the reason is not far to seek. Turbines are too often built by manufacturers without adequate hydraulic knowledge. The continued construction of turbines with thoroughly bad systems of regulation is a proof of the want of such knowledge. But most often the turbine fails from quite another cause. No adequate preliminary inquiry is made as to the local conditions in which a turbine is to be placed. Some previously manufactured size of turbine is selected and put in, with very little regard to the precise conditions in which it is to work. The variations of the fall, and the variations of the water supply are neither of them determined. Naturally it results that the proportions of the turbine are unsuitable, and the turbine is blamed, instead of its constructors.

American Turbines.—There is an opinion in some quarters that the best turbines are now American turbines. I should be sorry to underrate the value of American experience in turbine building, but on one point I can speak confidently, There is nothing new in principle in any American turbine. The Americans adopted in turn the Fourneyron, the Jonval, the inward-flow, and the mixed-flow turbines, and, so far as I can see, they have copied, without any material change, the turbines of Europe. There are amongst American turbines some so mal-constructed that they look as if they had come from the region behind the looking-glass. Others, no doubt, are excellent; but where they are best they most nearly approach ordinary European patterns. Many American turbines are mixed-flow turbines. This type of turbine is probably the cheapest to construct of all the pressure-turbines, and, like the inward-flow, permits a good mode of regulation. But there is absolutely no advantage in the efficiency to be got by twisting the water round a vane of double curvature, over that which can be got with a vane of simple curvature. In their purely practical aspect, the best American turbines are excellent. They are well manufactured, and attention is paid to designing them so that they can be cheaply erected.

Steam Turbines.—Steam under pressure will work a turbine as well as water under pressure, and with a no great alteration in the methods, a steam turbine can be designed like a water turbine. But there is a practical difficulty in the way of the adoption of steam turbines not yet overcome. For steam of, say, 30 lbs. pressure, the height corresponding to the pressure is about 60,000 feet. The velocity due to the head is such that the circumferential speed of the turbine must be about 1,000 feet per second. So soon as we can find a material strong enough and durable enough to stand an excessive speed of that kind, so soon we may have steam turbines much smaller and cheaper, and not less efficient than ordinary steam-engines.*

* The account of the Pelton wheel is from a paper by Mr. Hamilton Smyth in the Proc. Am. Soc. Eng.

MINERAL PRODUCTS OF THE UNITED STATES.

The second report on "The Mineral Resources of the United States," by Albert Williams, Jr., Chief of the Division of Mining Statistics and Technology, United States Geological Survey, is now in press, and will be issued shortly. This report is for the calendar years 1883 and 1884, and contains detailed statistics for these periods, and also for preceding years, together with much descriptive and technical matter. The following are the totals of the production of the more important mineral substances in 1884:

Coal.—The only statistics in which the trade is interested are those relating to the amount of coal which is mined for and reaches the market. There is, besides, a local and colliery consumption which is usually disregarded in statistics, and which ranges from 5 to 6½ per cent. of the total shipments. Of what may be called the commercial product, the quantities in 1884 were as follows: Pennsylvania anthracite, 30,718,293 long tons; bituminous and brown coal, lignite, and small lots of anthracite mined elsewhere than in Pennsylvania, 66,875,772 long tons; total, 97,594,065 long tons. The spot value of the commercial product was: Pennsylvania anthracite, $61,436,586; bituminous and all other coals, $70,219,561; total, $131,656,147. Including the local consumption, etc., the the total product in 1884 may be stated at 106,906,295 long tons, namely, 33,175,756 long tons of Pennsylvania anthracite, and 73,730,539 long tons of bituminous and all other coals; and the value at the mines was: Pennsylvania anthracite, $66,351,512; bituminous and all other coals, $77,417,066; total, $143,768,578. The total production (that is, including colliery and local consumption) of anthracite was 1,160,713 long tons less than in 1883, while its value was $10,905,543 less, the disproportionate decline in value being due to a fall of 25 cents per ton in spot price ($2.25 to $2). The total bituminous coal production increased 5,199,039 long tons over that of 1883, but its value was $4,820,734 less, the average valuation at the collieries having fallen from $1.20 to $1.05. The total output of all coals showed a net gain in tonnage of 4,038,326 long tons, and a decline in value of $15,726,277.

Coke.—There were 4,873,805 short tons of coke made in 1884, worth $7,-242,878 at the ovens. This production consumed 7,951,974 short tons of coal. The amount of coke made was 590,916 tons less than in 1883, and the value was $878,729 less.

Petroleum.—The production of crude petroleum in 1884 was 24,089,758 barrels of 42 gallons each, of which the Pennsylvania and New York oil fields produced 23,622,758 barrels. The total value at an average spot price of 85 cents, was $20,476,294. As compared with 1883 the production was 689,529 barrels greater; but the total value was $5,263,958 less, the average spot price having fallen from $1.10, or 25 cents per barrel.

Natural Gas.—The estimated value of the natural gas used in the United States in 1884 was $1,460,000, as against $475,-000 in 1883. The value is computed from that of the coal superseded by natural gas.

Iron.—The principal statistics for 1884 are as follows: Iron ore mined, 8,200,000 long tons; value at mine, $22,550,000. Domestic iron ore consumed, 7,718,129 long tons; value at mine, $21,224,854. Imported iron ore consumed, 487,820 long tons; total iron ore consumed, 8,-125,949 long tons. Pig iron made, 4,-097,868 long tons, a decrease of 497,642 tons as compared with 1883; value at furnace, $73,761,624, or $18,148,576 less than in 1883. Total spot value of all iron and steel in the first stage of manufacture, excluding all duplications, $107,-000,000, a decline of $35,000,000 from 1883. Fuel consumed in all iron and steel works, including blast furnaces, 1,-973,305 long tons of anthracite, 4,226,-986 long tons of bituminous coal, 3,833,-170 long tons of coke, and 62,110,660 bushels of charcoal, besides a notable quantity of natural gas. Limestone used as flux, 3,401,930 long tons; value at quarry, $1,700,965.

Gold and silver.—The Mint authorities estimate the production in 1884 at $30,800,000 gold, and $48,800,000 silver (coining rate); total, $79,600,000. This was an increase of $800,000 gold, and $2,600,000 silver, as compared with 1883. The gold production was equivalent to 1.489,049 troy ounces, and the silver to 37,744,605 troy ounces.

Copper.—The production in 1884, including 2,858,754 pounds made from imported pyrites, was 145,221,934 pounds, worth $17,789,687, at an average price of 12¼ cents per pound in New York City. The amount was 28,070,139 pounds greater than the production of 1883; but the value was $275,120 less than that for 1883, owing to the decline in price. In 1884, 4,224,000 pounds of bluestone (sulphate of copper, "blue vitriol") were made; worth, at 4.3 cents per pound, $181,632.

Lead.—Production, 139,897 short tons. Total value, at an average price of $75.32 per ton on the Atlantic seaboard, $10,537,042. The production was 4,060 tons less than that of 1883, while the decrease in value was $1,785,677. The production of white lead (carbonate) is estimated at about 65,000 short tons, worth, at 4⅞ cents per pound, $6,337,500, almost all of which was made from pig lead. The production of litharge and red lead has not been ascertained.

Zinc.—Production of metallic zinc, 38,544 short tons, worth, at an average price of 4.44 cents per pound in New York City, $3,422,707. The output was 1,672 tons greater than 1883, and the value increased $111,601. Besides the spelter and sheet zinc, about 13,000 short tons to zinc white (oxide) were made directly from the ore, the total value of which, at 3½ cents per pound, was $910,000.

Quicksilver.—Production, 31,913 flasks (of 75½ pounds net=2,441,344 pounds), or 14,812 flasks less than in 1883. Total value, at an average price of $29.34 per flask at San Francisco, $936,327, a decline of $317,305, as compared with the total value of the product of the previous year. During the year, 600,000 pounds of quicksilver vermilion were made, worth $288,000.

Nickel.—Production of nickel contained in copper-nickel alloy, 64,550 pounds, worth, at 75 cents per lb. $48,-412; an increase of 5,750 pounds, but a decline of $4,508 in total value, owing to the falling off in price.

Cobalt.—The amount of cobalt oxide

made in 1884 was about 2,000 pounds, as against 1,096 pounds made in 1883. Its value, at $2.55 per pound, was $5,100. The value of cobalt ore and matte cannot be ascertained, as it is chiefly dependent on the nickel contents.

Manganese.—The output of manganese ore in 1884 was about 10,000 long tons, or 2,000 tons more than in 1883. The total value, at $12 per ton at the mines, was $120,000, or about the same as in 1883, the average price having declined $3 per ton.

Chromium.—The production of chrome iron ore, all from California, was about 2,000 long tons, or about two-thirds as much as in 1883. At an average value of $17.50 per ton at San Francisco, the total value was $35,000.

Tin.—A little tin ore was taken out in the course of development work in Dakota, Wyoming, Virginia, and Alabama, but the only metallic tin made was a few hundred pounds from ore of the Black Hills (Dakota) mines made in sample tests at New York City pending the building of reduction works at the mines.

Platinum.—The amount mined in 1884 was about 150 troy ounces, worth, crude, $3 per ounce.

Aluminum.—The amount made in the United States in 1884 was 1,800 troy ounces, an increase of 800 ounces over the production of 1883. At 75 cents per ounce the total value was $1,350.

Building stone.—It is estimated that the value of the building stone quarried in 1884 was $19,000,000, as against $20,000,000 in 1883; the decline being due partly to dullness of trade and partly to the increased use of other structural materials.

Brick and Tile.—The output was about the same as in 1883, but as manufacturers cut down expenses still further, meeting a lower market, the total value is estimated at $30,000,000 as against $34,000,000 in 1883.

Lime.—There were 37,000,000 barrels (of 200 pounds) made in 1884, the average value per barrel at the kilns being not over 50 cents, or $18,500,000. The production was about 5,000,000 barrels greater than in 1883, but owing to the fall in price the total value was about $700,000 less.

Cement.—About 100,000 barrels (of 400 pounds) of artificial Portland cement were made, or 10,000 barrels more than in 1883; the total value, at $2.10 per barrel, being $210,000. The production of cement from natural cement rock was 3,900,000 barrels (of 300 pounds), or 200,000 barrels less than in 1883; worth, at 90 cents per barrel, $3,510,000. The total production of all kinds of cement was about 4,000,000 barrels, valued at $3,720,000.

Precious stones.—The estimated value of American precious stones sold as specimens and souvenirs in 1884 was $54,325, and the value of the stones sold to be cut into gems was $28,650; total, $82,975. About $140,000 worth of gold quartz was saved as specimens or made into jewelry and ornaments.

Buhrstones.—The value of the buhrstones yearly made in the United States is about $300,000.

Grindstones.—Dealers estimate the value of the grindstones made in 1884 at $570,000.

Phosphates.—The production of washed phosphate rock in South Carolina during the year ending May 31, 1884, was 431,779 long tons, worth $2,374,784, or 53,399 tons more than in the previous year, with an increase of $104,504 in value. The average spot price, $5.50 per ton, was 50 cents less than in the preceding year. The recent discoveries of phosphate rock in the adjoining States of North Carolina, Alabama, and Florida will probably lead to a still further increase in production. Of manufactured fertilizers, 967,000 short tons, worth $26,110,000, were made in the year ending April 30, 1884, and 1,023,500 short tons, worth $27,640,000, were made in the year ending April 30, 1885.

Marls.—In New Jersey about 875,000 tons, worth $437,500 at the pits, were dug in 1884. In addition, small quantities were produced for local use in some of the Southern States. The production is declining, owing to competition with fertilizers made from phosphate rock, etc.

Gypsum.—In the Atlantic States, from Maine to Virginia, 65,000 long tons of land plaster and 60,000 tons of stucco, total 125,000 tons, were made in 1884, of which nearly all was from Nova Scotia gypsum. The statistics for Michigan have not been reported, but the production did not vary greatly from that in 1883, in which year it was 60,082 short tons of land plaster and 159,100 barrels (of 300 pounds) of stucco. In Ohio, 4,217 short tons of land plaster and 20,307 barrels of stucco were produced. There was also a small production in other parts of the country; but the total amount of domestic gypsum used is not known.

Salt.—The production in 1884 was 6,514,937 barrels of 280 pounds (equivalent to 1,824,182,360 pounds, or 32,574,685 bushels, or 912,091 short tons, according to the unit used). The total value, computed on average wholesale prices at the point of production, was $4,197,734. The apparent output was 322,706 barrels greater than in 1883, while the value was $13,308 less; but the production figures do not include a considerable stock on hand in the Onondaga district, not officially reported because not inspected.

Bromine.—The production is estimated at 281,100 pounds, all from the Ohio and West Virginia salt district; worth, at 24 cents per pound, $67,464.

Borax.—Production about 7,000,000 pounds, or 500,000 pounds more than in 1883. The total value, however, was less than that of the product of 1883, being about $490,000 at San Francisco rates, as against $585,000 in 1883.

Sulphur.—No exact statistics. The production was only about 500 tons, worth about $12,000.

Pyrites.—About 35,000 long tons were mined in the United States, worth about $175,000 at the mines. Some 33,500 tons of imported pyrites were also burned, making a total consumption of 68,500 tons.

Barytes.—Full statistics not received. The production is estimated to have been about 25,000 tons; worth, at $4 per ton, unground, at the point of production, $100,000.

Mica.—The production of merchantable sheet mica, not including mica waste, was 147,410 pounds, valued at $368,525.

Feldspar.—The production was 10,900 long tons, or 3,200 tons less than in 1883. Its value at the quarries was $55,112.

Asbestos.—The amount mined was about 1,000 short tons, worth about $30,000.

Graphite.—Production nominal, the supply being drawn from the stock accumulated in 1883.

Asphaltum.—The annual production is about 3,000 tons, having a spot value of $10,500.

Alum.—About 38,000,000 pounds were made in the United States in 1884, or 3,000,000 pounds more than in 1883. At an average spot value of $1\frac{7}{8}$ cents per pound, the product was worth $712,500.

Copperas.—The amount made in 1884 was 15,500,000 pounds, worth, at 60 cents per hundredweight, $93,000.

Mineral Waters.—The sales of natural mineral waters in 1884 amounted to 68,720,936 gallons, valued at $1,665,490, an apparent increase of 21,431,193 gallons and $526,007 upon the figures for 1883. While the sales are undoubtedly increasing, it is possible that the excess in the reported quantity and value of the waters sold in 1884 as compared with 1883 may be partly due to the greater fullness of the returns for 1884. Besides the waters bottled and placed on the market there is a large local consumption, not included in the foregoing figures.

Totals.—As was remarked in the former report, it is impossible to state the total mineral product in any form which shall not be open to just criticism. It is evident that the production statistics of such incongruous substances as iron ore, metallic gold and silver, the spot value of coal mined and the market value of metallic copper after having been transported hundreds of miles, the spot value of a crude substance like unground, unrefined barytes, and the value of a finished product like brick (in which the cost of manufacture is the leading item), cannot well be taken as items in a general summary. The statistics have been compiled with a view to giving information on those points which are of most interest and utility, and are presented in the form usual in the several branches of trade statistics. The result is that the values stated for the different products are necessarily taken at different stages of production or transportation, etc. Theoretically perfect statistics of mineral products would include, first of all, the actual net spot value of each substance in its crudest form, as taken from the earth; and yet for practical purposes such statistics would have little interest other than the fact that the items could be combined in a grand total in which each substance should be rated on a fairly even basis. The following groupings, therefore, are presented with a full realization of the incongruity of many of the items. The grand total might be considerably reduced by substituting the value of the iron ore mined for that of the pig iron made, by deducting the discount on silver, and by considering lime, salt, cement, borax, etc., as manufactures. It will also be remarked that the spot values of copper, lead, zinc, and chrome iron ore are much less than their respective values after transportation to market. Still, the form adopted seems to be the only one which admits of a comparison of the total values of the mineral products from year to year.

METALLIC PRODUCTS OF THE UNITED STATES IN 1884.

	Quantity.	Value.
Pig Iron, long tons, spot value	4,097,868	$73,761,624
Silver, troy ounces, coining value	37,744,605	48,800,000
Gold, troy ounces, coining value	1,489,949	30,800,000
Copper, pounds, value at New York City (*a*)	145,221,934	17,789,687
Lead, short tons, value at New York City	139,897	10,537,042
Zinc, short tons, value at New York City	38,544	3,422,707
Quicksilver, flasks, value at San Francisco	31,913	936,327
Nickel, pounds, value at Philadelphia (*b*)	64,550	48,412
Aluminum, troy ounces, value at Philadelphia	1,800	1,350
Platinum, troy ounces, value crude at New York City	150	450
Total	....	$186,097,599

a Including copper made from imported pyrites
b Including nickel in copper-nickel alloy.

NON-METALLIC MINERAL PRODUCTS OF THE UNITED STATES IN 1884 (SPOT VALUES).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania..long tons (*a*)	73,730,539	$77,417,066
Pennsylvania anthracite ... do. (*b*)	33,175,756	66,351,512
Petroleum ... barrels	24,089,758	20,476,294
Building stone	....	19,000,000
Lime ... barrels	37,000,000	18,500,000
Salt ... do.	6,514,937	4,197,734
Cement ... do.	4,000,000	3,720,000
South Carolina phosphate rock ... long tons (*c*)	431,779	2,374,784
Limestone for iron flux ... do.	3,401,930	1,700,965
Mineral waters ... gallons sold	68,720,936	1,665,490
Natural gas	....	1,460,000
Zinc white ... short tons	13,000	910,000
Concentrated borax ... pounds	7,000,000	490,000
New Jersey Marls ... short tons	875,000	437,500
Mica ... pounds	147,410	368,525
Pyrites ... long tons	35,000	175,000
Gold quartz, souvenirs, jewelry, etc	....	140,000
Manganese ore ... long tons	10,000	120,000
Crude barytes ... do.	25,000	100,000
Ocher ... do.	7,000	84,000
Precious stones	....	82,975
Bromine ... pounds	281,000	67,464
Feldspar ... long tons	10,900	55,112
Chrome iron ore ... do.	2,000	35,000
Asbestos ... short tons	1,000	30,000
Slate ground as a pigment ... long tons	2,000	20,000
Sulphur ... short tons	500	12,000
Asphaltum ... do.	3,000	10,500
Cobalt oxide ... pounds	2,000	5,100
Total	....	$220,007,021

a The commercial product, that is, the amount marketed, was only 66,875,772 tons, worth $70,219,561.
b The commercial product, that is, the amount marketed, was only 30,718,293 tons, worth $61,436,586.
c Year ending May 31.

Résumé of the values of the Metallic and Non-metallic Mineral Substances Produced in the United States in 1884.

Metals	$186,097,599
Mineral substances named in the foregoing table	220,007,021
	406,104,620
Fire-clay, kaolin, potter's clay, common brick clay, terra-cotta, building sand, glass sand, limestone used as flux in lead smelting, limestone in glass making, iron ore used as flux in lead smelting, marls, (other than New Jersey), gypsum, tin ore, antimony, iridosmine, mill-buhrstone and stones for making grindstones, novaculite, corundum, lithographic stone, talc and soapstone, quartz, fluor spar, nitrate of soda, carbonate of soda, sulphate of soda, native alum, ozocerite, mineral soap, strontia, infusorial earth and tripoli, pumice-stone, sienna, umber, etc., certainly not less than	7,000,000
Grand total	$413,104,620

The *production in* 1884, 1883, *and* 1882 *compared.*—Tables showing the quantities and values of the mineral products of the United States in 1883 and 1882 are appended for comparison. From these it appears that the total value of the metals and minerals produced in 1884 was $39,100,008 less than in 1883, and that the decline in 1883 from 1882 was $3,012,061; that is, the falling off in value began on a small scale in 1883, but was accented in 1884. The net decline as will be seen by reference to the tables, has been due rather to a depression in price than to a decrease in quantity; indeed, several important substances show a decided increase in production, notwithstanding the general dullness of trade. The overproduction, taking the whole field into consideration, has been less than was generally feared.

Metallic Products of the United States in 1883.

	Quan.	Value.
Pig iron, long tons, spot value	4,595,510	$91,910,200
Silver, troy ounces, coining value	35,733,622	46,200,000
Gold, troy ounces, coining value	1,451,249	30,000,000
Copper, pounds, value at New York City (*a*)	117,151,795	18,064,807
Lead, short tons, value at New York City	143,957	12,322,719
Zinc, short tons, value at New York City	36,872	3,311,106
Quicksilver, flasks, value at San Francisco	46,725	1,253,632
Nickel, pounds, value at Philadelphia (*b*)	58,800	52,920
Aluminum, troy ounces, value at Philadelphia	1,000	875
Platinum, troy ounces, value, crude, at New York City	200	600
Total	....	$203,116,859

a Including copper made from imported pyrites.
b Including nickel in copper-nickel alloy.

NON-METALLIC MINERAL PRODUCTS OF THE UNITED STATES IN 1883 (SPOT VALUES).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania....long tons (*a*)	68,531,500	$82,237,800
Pennsylvania anthracite..................long tons (*b*)	34,336,469	77,257,055
Petroleum..................................barrels	23,400,229	25,740,252
Building stone..................................	....	20,000,000
Lime......................................barrels	32,000,000	19,200,000
Cement.................................... do.	4,190,000	4,293,500
Salt...................................... do.	6,192,231	4,211,042
South Carolina Phosphate Rock...........long tons (*c*)	378,380	2,270,280
Limestone for iron flux.....................long tons	3,814,273	1,907,136
Mineral waters.........................gallons sold	47,289,743	1,139,483
Concentrated borax..........................pounds	6,500,000	585,000
New Jersey marls.........................short tons	972,000	476,000
Natural gas....................................	....	475,000
Mica.......................................pounds	114,000	285,000
Pyrites..................................long tons	25,000	137,500
Manganese ore............................long tons	8,000	120,000
Gold quartz souvenirs, jewelry, etc...................	....	115,000
Crude barytes............................long tons	27,000	108,000
Precious stones.................................	....	92,050
Ocher....................................long tons	7,000	84,000
Bromine....................................pounds	301,100	72,264
Feldspar.................................long tons	14,100	71,112
Chrome iron ore............................ do.	3,000	60,000
Graphite...................................pounds	575,000	46,000
Asbestos................................short tons	1,000	30,000
Sulphur................................... do.	1,000	27,000
Slate ground as a pigment.................long tons	2,000	24,000
Asphaltum...............................short tons	3,000	10,500
Cobalt oxide...............................pounds	1,096	2,795
Total..	....	$241,087,769

a The commercial product, that is, the amount marketed, was only 65,268,095 tons, worth $78,321,714.
b The commercial product, that is, the amount marketed, was only 31,793,027 tons, worth $71,534,311.
c Year ending May 31.

RÉSUMÉ OF THE VALUES OF THE METALLIC AND NON-METALLIC MINERAL SUBSTANCES PRODUCED IN THE UNITED STATES IN 1883.

Metals..	$203,116,859
Mineral substances named in the foregoing table....................	241,087,769
	444,204,628
Estimated value of mineral products unspecified....................	8,000,000
Grand total..	$452,204,628

METALLIC PRODUCTS OF THE UNITED STATES IN 1882.

	Quantity.	Value.
Pig iron, long tons, spot value.........................	4,623,323	$106,336,429
Silver, troy ounces, coining value.....................	36,197,695	46,800,000
Gold, troy ounces, coining value......................	1,572,186	32,500,000
Copper, pounds, value at New York City (*a*)...........	91,646,232	16,038,091
Lead, short tons, value at New York City...............	132,890	12,624,550
Zinc, short tons, value at New York City..............	33,765	3,646,620
Quicksilver, flasks, value at San Francisco............	52,732	1,487,042
Nickel, pounds, value at Philadelphia (*b*)............	281,616	309,777
Antimony, short tons, value at San Francisco..........	60	12,000
Platinum, troy ounces, value, crude, at New York City.	200	600
Total..	....	$219,755,109

a Including copper made from imported pyrites.
b Including nickel in copper-nickel alloy.

NON-METALLIC MINERAL PRODUCTS OF THE UNITED STATES IN 1882 (SPOT VALUES).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania....long tons (*a*)	60,861,190	$76,076,487
Pennsylvania anthracite..................long tons (*b*)	31,358,264	70,556,094
Crude petroleum.........................barrels (*c*)	30,053,500	23,704,698
Lime.......................................barrels	31,000,000	21,700,000
Building stone..............................	....	21,000,000
Salt.......................................barrels	6,412,373	4,340,140
Cement.................................... do.	3,250,000	3,672,750
Limestone for iron flux......................long tons	3,850,000	2,310,000
South Carolina phosphate rock............long tons (*d*)	332,077	1,992,462
New Jersey marls.........................short tons	1,080,000	540,000
Concentrated borax.........................pounds	4,236,291	338,903
Mica .... do.	100,000	250,000
Natural gas....................................	....	215,000
Ocher ....long tons	7,000	105,000
Soapstone.................................short tons	6,000	90,000
Crude barytes............................long tons	20,000	80,000
Precious stones................................	....	75,000
Gold quartz souvenirs, jewelry, etc................	....	75,000
Pyrites...................................long tons	12,000	72,000
Manganese ore............................ do.	3,500	52,500
Chrome iron ore........................... do.	2,500	50 000
Asbestos..................................short tons	1,200	36,000
Graphite...................................pounds	425,000	34,000
Cobalt oxide.............................. do.	11,653	32,046
Slate ground as a pigment..................long tons	2,000	24,000
Sulphur..................................short tons	600	21,000
Asphaltum................................ do.	3,000	10,500
Corundum................................. do.	500	6,250
Pumice-stone............................. do.	70	1,750
Total......................................	....	$227,461,580

a The commercial product, that is, the amount marketed, was only 57,963,038 tons, worth $72,453,797.
b The commercial product, that is, the amount marketed, was only 29,120,096 tons, worth $65,520,216.
c Pennsylvania and New York field only; the outside production was very small.
d Year ending May 31.

RÉSUMÉ OF THE VALUES OF THE METALLIC AND NON-METALLIC MINERAL SUBSTANCES PRODUCED IN THE UNITED STATES IN 1882.

Metals..	$219,755,109
Mineral substances named in the foregoing table....................	227,461,580
	447,216,689
Estimated value of mineral products unspecified................ ...	8,000,000
Grand total	$455,216,689

This total for 1882 has been increased, by corrections and additions, $1,304,283 upon the figure given in the first report of this series, which was $453,912,406.

TECHNICAL EDUCATION—SIBLEY COLLEGE.

Sibley College is the School of Mechanical Engineering, and of Mechanic Arts, of Cornell University. It has a complete organization, separate buildings, containing lecture-rooms, drawing rooms, museums of collections of machines and apparatus, and workshops, in which instruction is given in the working of wood and of the metals. It is organized as follows:

At the head of the college is a presiding officer, called the "Director," who, by direction and authority of the Trustees, will plan the several courses of instruction, and determine upon the best methods of tuition in the several departments of the college, and who will see the whole system of instruction kept in operation, in accordance with the plans laid out by him, and approved by the authorities of the University. He is made responsible for the efficiency of the material and personnel of the college, for its proper organization and administration, and for its operation in accordance with the policy and general methods of the University. In all such matters, and in those in which the college is brought into contact with the workings of the University, and the departments exterior to itself, a special Faculty is consulted, as an advisory body, and the general Faculty is expected to assist in effecting all arrangements by which the co-operation of such departments is to be secured.

The college is divided into three principal departments, each of which is presided over by a professor skilled in the subject, instruction in which is directly conducted by him and his assistants. These departments are "Mechanical Engineering," including a Mechanical Laboratory, in which experimental work and investigations are conducted; a department of "Practical Mechanics," or shopwork, and the department of "Drawing and Machine Design." The first named is presided over by the Director, who is also the Professor of Mechanical Engineering. The two other departments will be directly managed by professors conversant with the special work falling within their lines. Assistants and skilled workmen are employed in these several departments as needed.

When fully organized and in operation as intended, the course of instruction in Sibley College will, as a rule, be arranged with reference to the demands of students desiring ultimately to take the degree of "Mechanical Engineer." The lecture-room course of instruction consists of the study, by text-book and lecture, of the materials used in mechanical engineering—especially of steel and iron—the valuable qualities of these materials being exhibited in the mechanical laboratory, by the use of the various kinds of testing machines, as well as by examination of specimens of all the most familiar grades, of which samples are seen in the cases of the museums and lecture-rooms. The theory of strength of materials is here applied, and the effects of modifying conditions, such as variation of temperature, frequency and period of strain, method of application of stress are illustrated. This course or study is followed, or accompanied by instruction in the science of pure mechanism, or kinematics, which traces motions of connected parts, without reference to the causes of such motion, or the work done, or the energy transmitted. This study is conducted largely in the drawing-rooms, where the successive positions of moving parts can be laid down on paper. It is illustrated, in some directions, by the set of kinematic models, known as the Reuleaux model, the only complete collection of which, in the United States, is found in the museums of Sibley College.

The study of Machine Design properly succeeds that of pure mechanism, just described, and includes the determination of the general dimensions, and of the forms and proportions of the principal parts of machinery, both as fixed by the strength of material and form of the members designed, and by the method of connection to adjacent parts of the construction. This study also is largely conducted in the drawing rooms, and is directed by an instructor familiar, practically as well as theoretically, with the designing and proportioning of machinery. The study of mathematical principles, and of the strength of materials as applied in this portion of the work, is pursued at an earlier period of the course of preparation for these professional studies, in the several other departments of the University to which such preparatory work properly belongs.

The closing work of the course consists in the study, by text-book and lecture, of the theory of the steam-engines and other motors, including both the mechanical and the thermodynamic principles, and an examination of the structure of that class of machinery; this course of instruction being followed, as far as may be found practicable, by exercises in designing and proportioning such engines. The last term of the regular four-years' course is devoted, mainly, to the preparation of a graduating thesis, in which the student is expected to exhibit something of the working power and the knowledge gained during his course. This thesis may be either a treatise upon some subject having professional interest, and which has not been hitherto fully treated, or an account of some new and useful form of machine devised by the writer, and of which he will present the theory and method of design; or it may be an account of some original design of works fitted for manufacturing specified products, or an investigation having direct and practical bearing upon problems of importance arising in the course of professional work. Of these several kinds of thesis, the last two named are given, as a rule, highest value. The thesis is rejected, and the student is not given his diploma, should his production not give evidence of originality and strength, and of having profited, to a very creditable extent, by the opportunities which have been offered him.

The general course is accompanied by systematic instruction, as already stated. in the drawing rooms and in the workshops.

The course of instruction in mechanical drawing is progressive, from geometrical drawing to the designing of machinery and the making of working drawings. The aim is to familiarize the student with methods adopted in the best drawing offices. Working drawings and blue prints have been obtained from our most prominent engine and machine builders, whose practice is thus shown in the clearest possible way. A large collection, containing several hundred drawings, selected from the best technical schools abroad, also aids in this work.

The aim of the instruction in shop-work is to make the student, as far as time will permit, acquainted with the most approved methods for the construction and inspection of machinery. Every student is required to devote nine hours per week to work in the shops, or about thirty days during each year.

This course begins with a series of exercises in wood-working, each of which is intended to give the student familiarity with a certain application of a certain tool, and the course of exercises, as a whole, is expected to enable the industrious, conscientious, and painstaking student to easily and exactly perform any ordinary operation familiar to the carpenter, the joiner and the pattern-maker. Time permitting, these prescribed exercises are followed by practice in making members of structures, joints, and of small complete structures, and of patterns, their core boxes, and other constructions in wood.

The wood-working and pattern shop is thoroughly equipped for teaching the use of all ordinary tools and machines for working wood. Particular attention will be paid to the details of pattern making.

This course is expected not only to give the student a knowledge of the methods of the carpenter and the pattern maker, but to teach him how to handle tools, and to give him that manual skill in the handling of machines which will permit him to enter the machine shop, and there to quickly acquire familiarity and skill in the manipulation of the metals, and in the management of both hand and machine tools, as used in the working of such metals.

The instruction in the machine shop, in the foundry, and the blacksmith shop is intended to be carried on in substantially the same manner as in the wood-working course, beginning by a series of graded exercises, which will give the student familiarity with the tools of the craft and with the operations for the performance of which they are particularly designed, and concluding by practice in the construction of parts of machinery, and, time permitting, in the building of complete machines which may have a market value. The time allowed for work in the shop is not, and cannot well be, sufficient to teach the student all the methods of the several trades, or to make him, unless an exceptionally good mechanic by nature, a skilled workman; but it is hoped that the amount of time given to shop work may be hereafter somewhat enlarged, and that the course may be gradually extended in length, and given increased efficiency in method. With the time now given, however, the instruction in this, the department of the mechanic arts, is found to be of very great value to the student.

The mechanical laboratory will be devoted to making tests and experiments. The apparatus will consist of experimental engines and boilers, machines for testing the strength of materials, friction and lubricants, and of friction and transmitting dynamometers, etc., etc.

The work in this department will be conducted by an instructor familiar with its apparatus and with the best methods of work, and who will plan a systematic course of instruction which is intended to give the student not only skill in the use of apparatus of exact measurement, but to teach him also the best methods of research, and to give him a good idea of the most effective methods of planning and of prosecuting investigations, with a view to securing fruitfulness of result with minimum expenditure of time and money. In this, as in every other department, the instructors are expected to keep in view the more important methods of practical work coming to the engineer in his daily practice. The object of all the theoretical instruction is to give the student power to solve the problems arising in every-day life, and to make him familiar with the best methods of uniting theory and practice in such manner as to enable him to reach a defined object most directly, and with greatest certainty.

The professional work of the college is based upon courses of preparatory study, which include the usual branches as taught in the high schools and colleges of the country, and exceptionally extended and thorough courses of instruction in mathematics and in the physical sciences. These preparatory studies are pursued in the various appropriate departments of the University, as described in the "Register," and instruction is facilitated by the use of a very extensive collection of apparatus, illustrating the facts and principles presented to the students by the lecturers in each department in which such apparatus can be so used.

Students who have completed the course of study above outlined, who have the time and means, and who desire advanced instruction in either of several lines of mechanical engineering, after graduation, may continue their studies through a fifth year, taking up the courses prescribed in the register, and a certain number of optional studies, which are selected with a view to making the year as profitable, professionally, as possible. The courses now ready are those in Marine Engineering and Naval Architecture, in Steam Engineering, in the Mechanical Engineering of Railroads, and in special laboratory investigation. Should the student desire to pursue his studies still further, he may do so as a resident graduate, taking such lines of reading and of experimental investigation as he may consider best, still subject, however, to the approval and supervision of the Director and of the head of the department in which his work may be carried on. The details of all courses of instruction, and of all lecture courses open to the student, whether graduate or undergraduate, are described in the Register of the University, which is mailed to all applicants by the Treasurer. It will be seen that laboratory practice in chemistry and physics, which is invariably found to have peculiar value to the mechanical engineer, forms a very important and extended part of the scientific instruction assigned to the student in every department of professional work in engineering.

Sibley College was founded as a college of the Mechanic Arts, and is intended by the Trustees of the University to be made not only a school of arts and trades, but a college of engineering, in which schools of the mechanic arts, and of the various branches of mechanical engineering, shall be developed, as rapidly and as extensively, as the means placed at the disposal of the Trustees of the University, and a demand for advanced and complete courses of instruction, shall allow. The courses now ready will be supplemented by other and more advanced courses, from time to time, as the number of students applying for advanced instruction shall justify further expansion ; and it is hoped and anticipated that, in time, the college may embrace schools of every branch of mechanic arts, and of mechanical engineering, which may assume prominence in connection with the development of the great industries of the country. Its buildings and equipments are already extensive and remarkably well adapted to the work to be done.

The buildings of Sibley College have been erected and presented to the University by the Hon. Hiram Sibley, of Rochester, N. Y., to whose intelligent and patriotic liberality the University is also indebted for the workshops, tools, and nearly all of the illustrative apparatus. The Sibley professorship of Practical Mechanics and Machine Construction is sustained by an endowment, which is another of the gifts of the same friend of the University.

The main building of Sibley College is constructed of stone, and is 160 feet in length and 40 in breadth, and three stories in height. It contains the lecture-rooms, drawing-rooms, and museums of the college, and is connected with a series of workshops, including a wood shop, machine shop, forge, foundry, and mechanical laboratory, with rooms devoted to various other purposes, and with the janitor's house.

The wood-working shop is supplied with all needed hand and power tools, work-benches, and accessories sufficient for sections of classes up to twenty-five or more in number, should it be found advisable to work so many together.

The machine shop is supplied with lathes of various kinds, planers, grinding, drilling, and shaping machines, a universal milling machine fitted for cutting plane, bevel and spiral gears, spiral cutters, and twist drills, with additional tools and attachments for graduating scales and circles and for working various forms and shapes.

In addition to the usual hand and lathe tools, there are instruments of the greatest accuracy consisting of standard surface-plates, straight-edges, and squares of various sizes ; a standard measuring machine reading to the ten-thousandth of an inch, a universal grinding machine for producing true cylindrical and conical forms, and a set of Betts' standard gauges.

The smithy contains ten forges of the most approved pattern, and corresponding outfits of smiths' tools. The instruction embraces forging, welding, tempering, etc.

The foundry is equipped for giving thorough instruction in loam and sand moulding, and the casting of iron and brass. The cupola for melting iron is a Colliau's improved, with a capacity of one ton per hour. There are also a crucible furnace for melting brass, a core oven, a rattler, and the other usual foundry appliances.

The mechanical laboratory is supplied with several kinds of testing machines, including those made by Fairbanks & Co., for tests of beams ; by Riehle Brothers, for rapid work in tests by tension ; by Olsen & Co.. for slower, but more precise, work in determining, especially, the elastic properties, and the modulus of elasticity of materials ; and by the Pratt & Whitney Co., the latter being an "Autographic Recording Testing Machine," used in making special investigations of the properties of the materials used in construction. A Brown and Sharpe machine, for testing the strength and ductility of fibrous materials, completes the list of testing machines. Other machines are used, in the course of laboratory instruction, for determining the value of lubricants, their endurance under work, and their coefficients of friction. Dynamometers will be brought into use in measuring the power of prime-movers, and the work done in driving machinery. Steam-engine indicators, of which all the most familiar kinds are represented in the collections, are applied to testing steam-engines, and other heat motors ; and steam gauges, counters, and other minor kinds of testing apparatus, and instruments of exact measurement, are made, in various ways, to illustrate the course of instruction in this line of work. The test trials of steam-boilers, and the testing of other apparatus and machines, to determine their capacity, efficiency, and adaptation to their intended purposes of application, form part of this course, and the needed apparatus is provided here as required. The collection of mechanical laboratory apparatus in these departments is already exceptionally rich and complete, and is expected to be steadily increased by annual accessions by purchase and gift from members of the pro fession and others interested in this branch of technical education.

The museums of Sibley College contain the Reuleaux collection, illustrating the course of instruction in mechanism ; a very interesting collection of other apparatus having a similar use ; various forms of steam-engine governors ; models illustrating the forms of parts of machines, and of complete constructions ; a large variety of machinery, such as is seen in the market, contributed, in most cases, by the makers ; and many objects which cannot be so well classified, which are, however, all of interest to the student of ma chinery. The drawing rooms are carefully fitted up with a view to convenience and efficiency of work in instruction, and are supplied with all the instruments, models, casts, and other material needed. Students are also expected to make free use of the collections in the museums, and to sketch in the workshops, as they acquire expertness in the handling of instruments, and power in the use of the hand. The lecture rooms are fitted up, each with a view to the work to be done, and contain cases of apparatus and models, drawings, wall charts, and samples of materials in use in the arts and trades, all so arranged that the instructor may bring them before the class with least possible loss of time, or expenditure of labor.

A lyceum is also fitted up, for the use of students who are enrolled in the association to which it is assigned, in which weekly debates are carried on, and in which the working library of the department may be gathered.

Supplementing the regular course of instruction, a series of lectures will be delivered in the lyceum and in lecture rooms, from time to time, by members of a body of "Non-Resident Lecturers," who have been chosen from among the most distinguished men of the profession. These gentlemen choose their own subjects, and times of lectures, and their own method of presentation of the subject selected. They will, in some cases, deliver formal lectures, in others open the regular debates in the lyceum, in others give interesting talks to the classes in the lecture rooms, in connection with the work which may be then in hand. In the debates, in which the students are expected to take part freely, the discussion will take such direction as those present may find most attractive and profitable. The formal lectures may, or may not, be followed by debate, as may, at the time seem, in the opinion of the lecturer and of the director, best.

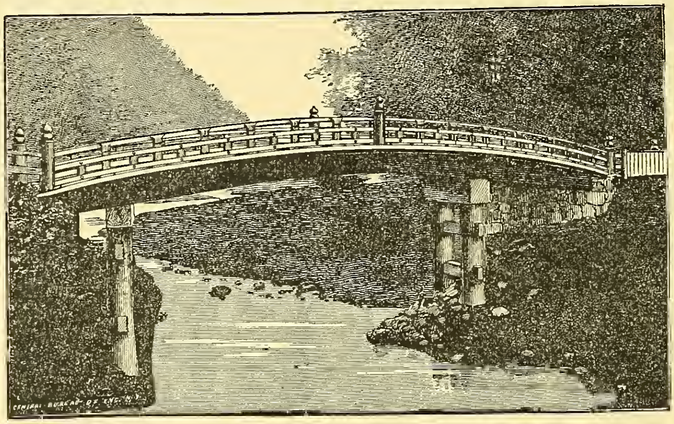
The preceding account of Sibley College represents the present condition of the institution, and the form of its courses of instruction, and indicates what is the intent of the Trustees and of the officers of the University, and of Sibley College, in regard to its position and development. As experience may yield suggestions, and may throw more light upon the possible future of the college, the plans here outlined will be subject to modification, and, it is hoped, to continuous improvement. The announcement here made is, to that extent, provisional. It is, however, the full intention of the Trustees to endeavor to carry out the desires of the Founder, and the policy of the University, as defined by its charter, in such manner as shall secure to students entering this institution opportunities of study, and of acquiring a knowledge of the facts and principles, and of the practice, of mechanical engineering, in whatever branch they may desire to work, such as can nowhere else be excelled, and to promote the growth of the schools of engineering and mechanic arts constantly, rapidly, and healthfully, so as to secure, in their operation, an efficient means of promoting every great industry of the country, while giving to every citizen the means of educating his children in the most useful and desirable directions.

The Director of Silby College is Professor Robert H. Thurston, late of Stevens Institute of Technology.

AN ORIENTAL CANTILEVER BRIDGE.

A LETTER from Yokohama, Japan, bearing date October 6th, gives the following description of an old bridge constructed by native engineers. The cut herewith presented was prepared from a photograph enclosed in the letter.

The writer evidently shared the popular but erroneous impression that engineers had urged the claim of novelty in the cantilever principle.



The following is the description *verbatim*:

"At the Sacred City of Nikko, the other day, I was rather amused and interested at seeing a fine and very costly bridge of cantilever construction—abutments of hewn stone, shore piers hewn granite, octagonal, monolithic, mortised for stone girders; monolithic plate beam to receive wooden superstructure. The stringers are fastened into the abutments, balance over the stone beam, but do not reach, by considerable distance, the gap being fitted by middle stringers let into the shore stringers.

"The Niagara Bridge is a mere amplification of this one, built before America was settled, as a religious duty, very expensive, of thick, red lacquered work, and, like a bridge of angels, its planks are never profaned by the feet of the laity. But it seems queer-like, to come away here to find our new inventions very old."

FARADAY is said to have estimated that there was no more electrical work in a lightning flash than would decompose a drop of water. It must take much more electricity, if this is true, to decompose a drop of water than to do a vastly heavier amount of work. Mr. W. Bellasis writes from Roehampton, August 30: "In case it has escaped notice, an opportunity now offers of witnessing in Richmond Park a truly awful spectacle. On the 6th a storm, scarcely observed elsewhere, burst upon the park. There was but one flash of lightning, which, singling out two fine oak trees, completely destroyed the top portion of one and shattered to pieces the solid base of the other, depositing the immense upper part, neatly severed and intact, some feet away. The explosion must have been terrific, as trees close by are damaged by the large splinters which, dried up and sapless, lie about in all directions."

PHYSIOGRAPHY.

By JOHN EVANS, Assoc. Inst. C. E.

A Lecture delivered before the Institution of Civil Engineers.

The Council of the Institution of Civil Engineers having determined on the delivery of a course of lectures on the Theory and Practice of Hydromechanics have done me the honor of requesting me to give the first of these lectures, and have suggested "Physiography" as my subject. At the time that I expressed my willingness to comply with this request, I hoped that I should be able to find sufficient spare hours to do some justice to the subject, but, unfortunately, owing to the absence of the President of the Royal Society, unexpected duties have devolved upon me, and the small modicum of leisure which my ordinary avocations allow me has been considerably cut down. I must, therefore, beg for some indulgence if in the following remarks I seem to treat my subject in an inadequate manner, and do not in some respects enter into the amount of detail which might not unreasonably have been expected.

But what is my subject? The word "Physiography"—for which as a title to my lecture I must deny all personal responsibility—is one of very wide import, and has been defined in the dictionaries as meaning "a description of nature, or the science of natural objects." I shall not attempt to accept the word in this wide sense, or the limits of one, or even of a dozen lectures, would not suffice for the treatment of the subject. And, moreover, it has already been admirably worked out by Professor Huxley in his course of lectures at the London Institution, which have been expanded into a most instructive volume, with the title "Physiography," a work which I have found of some service in preparing for this evening. What I hope to do, is to bring before you such portions only of this great subject as bear more especially on the supply of that indispensable necessary of life with which in various ways the lecturers who follow after me will have to deal, and I must, moreover, limit myself, as far as possible, to the phases of nature which may be observed in our own country.

The water which we consume for our daily use is usually derived from one of three sources—springs,—streams, rivers or lakes,—or reservoirs of some kind in which the rainfall is artifically stored. In all cases, however, the water comes to us more or less immediately from the clouds, and they in turn are fed by evaporation from different parts of the surface of the globe. The principal source whence the air derives its moisture is no doubt the ocean, from and toward which there is a constant circulation of water. As was said by the wise man of old:* "All the rivers run into the sea, yet the sea is not full; unto the place from whence the rivers come, thither they return again."

The air, then, is the great conductor of moisture from the sea and other sources to the springs and streamlets which feed the rivers, and the term "atmosphere"—the sphere of vapor—fittingly describes under one of its most beneficent functions the attenuated fluid which envelops our globe. I need hardly enter into the chemical nature of water, which consists of oxygen and hydrogen in the proportion of one to two, nor into that of air, which is, in fact, a mixture of about one part of oxygen-gas, with about four of nitrogen. To speak accurately, if we take 100 cubic feet of pure air, they will consist of 20.9 feet oxygen and 79.1 feet of nitrogen. If, on the other hand, we take 100 lbs. of pure air, it will be found that they consist of about 23 lbs. of oxygen and 77 lbs. of nitrogen. Air, however, as a rule, is not absolutely pure, but usually contains about four parts in the one thousand of carbonic-acid gas. as well as smaller proportions of ammonia, hydrogen and nitric acid. These may all have some slight effect on water falling through the air, but in considering the air as an absorbent of aqueous vapor, the minor constituents may be entirely disregarded. Practically, the air is never free from this aqueous vapor, for, how-

* Ecclesiastes i. 7.

ever dry it may appear, yet, when tested by powerful absorbents of moisture. water is constantly found present. The hotter the air the more capable it is of absorbing moisture and holding it in invisible suspension, we might almost say in solution. On the coldest day, however, the air retains some power of absorbing moisture, and will even carry it off from snow or from a lump of ice. As water itself, under ordinary circumstances, is converted into steam at a temperature of about 212° Fahrenheit, it is evident that with air at this or a higher temperature an invisible admixture of air and water might exist in almost any proportions. For it must be borne in mind that the ordinary conception of steam being visible is entirely erroneous. It is not until it has to some extent been condensed and reduced into small particles of water that steam assumes a visible consistence. If, on a bright day, we watch the steam blowing off from the safety-valve of a locomotive engine, we can observe three phases. Close to the valve there is little or no appearance of vapor, next we can observe volumes, in fact clouds, of visible steam being gradually formed, and as these are wafted away in feathery streaks by the wind they gradually disappear, the vapor having been absorbed and incorporated in the air, to be again deposited in the form of a visible cloud and eventually of rain at some future and possibly long distant time.

The quantity of moisture present in the air varies considerably in different countries and at different seasons. Here, in England, it is said that the average proportion of water present in the air is about $1\frac{1}{2}$ per cent. When the air at an ordinary temperature is nearly saturated, a slight reduction of heat suffices to make the moisture visible. How often do we not observe a mist rising, as it is called, towards sunset, after a bright warm day; and how often have we not seen the morning's mist, and even the clouds at a higher level, gradually disappear under the genial influence of the sun's rays.

The power of the air to carry off vapor has been put to the test by various experimental researches. In our own country, Howard, at Plaistow; Greaves, at Lea Bridge; Laws and Gilbert, at Rothamstead, and others, have investigated the subject. From shallow vessels at Plaistow, and from a larger surface of water at Lea Bridge, the annual evaporation was about 21 inches per annum, and, as might be expected, the quantity varied at different seasons of the year. Speaking roughly, it was about as follows:—January to March, 4 inches; April to May, 8 inches; June to September, 7 inches; October to December, 2 inches. At Dijon, about 26 inches were carried off from the surface of large vessels of water. Extensive observations made in Denmark show about 28 inches from water, 30 inches from short grass, and 44 inches from long grass.

In hotter regions the evaporation must be greater still; and I may just refer to the Dead Sea, into which the river Jordan is constantly flowing, and which, notwithstanding, is kept by evaporation at a level of more than 1,300 feet below that of the Mediterranean. Even the Mediterranean itself affords another instance of the wonderful power of the sun; for, notwithstanding the volume of water poured into it and the inland seas connected with it by the large rivers, such as the Rhone, the Po, the Danube, the Dnieper, the Don, and the Nile, this accession to its waters appears to be insufficient to keep pace with the evaporation from its surface, as notwithstanding occasional outward undercurrents, there is almost constant inset of the current through the Straits of Gibraltar. At Madras, it has been found that there is an annual evaporation of about 90 inches; and from a reservoir at Nagpoor, evaporation went on at the rate of one-fifth of an inch per diem, so that 48 inches disappeared in the course of two hundred and forty days. At Dublin, on the average of two years, Dr. Haughton found that the evaporation fell short of the rainfall by only 1 inch. In fact, Mr. R. H. Scott thinks that in nearly all parts of the globe, the evaporation from a free water surface is on the average about equal to the rainfall. The effect of wind is largely to increase the evaporation, and the hot winds of the equatorial regions, acting on the surface of a warm sea, become highly charged with vapor. It is, indeed, mainly from the surface of the ocean that the supply of aqueous vapor in the atmosphere must be derived. The fine warm weather which dries up a land surface until but little moisture is left to evaporate, makes the air which is brought in contact with the waves of the sea all the more avid to receive water, of which it then finds no stint. How readily the air parts with some of the moisture suspended in it, when brought in contact with a cold surface, is well shown by the hackneyed example of a glass of cold water brought into a warm room. The effect of currents of colder air meeting warmer currents fairly charged with moisture is first evinced by the condensation of minute particles of water, which, though still in suspension in the atmosphere are visible in the form of cloud, mist or fog. A greater or more continued chill causes these particles to increase in size, coalesce, and descend as rain, hail or snow.

In falling from the clouds, rain increases in quantity as it descends, probably by the absorption of vapor, or of minute particles of water in the state of mist. Experiments have shown that this increase is very marked. Even at 3 feet from the ground there is said to be two per cent. less of rain than at the surface; at 20 feet, twelve per cent.; and at 50 feet, twenty-three per cent. It is, nevertheless, somewhat doubtful whether this law of increase universally holds good. While, however, in an open plain there is less rain at a considerable height above the ground than at the surface, somewhat different conditions prevail in mountainous districts, for the actual amount of rainfall increases as a rule as we ascend the slope of a mountain. Mountain ranges, indeed, are the great condensers of atmospheric moisture, and the amount of rainfall of any country is in the main dependent on the position of these ranges, and the prevailing direction of the winds.

India affords a good example of this fact, as the trade-winds, or "monsoons," as they are there called, exhibit great regularity in their occurrence. From the end of October to the end of April there is little or no rain on the western coast, but during the other six months, after the monsoons have set in, rain falls in abundance. At Bombay, near the sea-level, the most rainy months are those of June and July, during which from 40 to 50 inches annually fall. During the whole of the rainy season the average of seven stations at the sea-level in the Bombay Presidency is about 80 inches. At an elevation of about 900 feet in the Southern Concan Hills or Western Ghâts there is an increase to about 135 inches, and at Mahabuleshwur, at a height of 4,500 feet, and at a distance of 130 miles from the sea, the annual fall is over 250 inches. It is rarely that the hot stratum of aqueous vapor brought from the equator by the south-west monsoon floats at a higher level than this. In dashing against the precipitous western face of the Ghats much of the warm stratum is thrown up among the colder layers of air at higher levels; but a little is carried eastward to be condensed by the Himalayas. So effectually does this high range do its work that the great plain of Tibet to the east may be regarded as rainless. In the same manner while the great central plains of Spain, at an elevation of 1,200 feet or more above the sea, are during the summer months pinched with drought, the seaward face of the mountains that skirt the Bay of Biscay are clothed with verdure and rarely in want of rain.

Great as are the variations in the rainfall in India, they may be equaled, if not exceeded, by those in the British Isles. With us the Gulf Stream with its warm current seems to play an important part in supplying vapor to the atmosphere, and in charging our southern winds with moisture. A glance at a Hyetographical or Rainfall map, such as that prepared by Mr. G. J. Symons, of which he has kindly lent a copy, will at once show how disproportionate is the amount of rain which falls on the western and southern shores of England as compared with that on the eastern. Along our western shores the usual fall is from 40 to 50 inches, and in many districts from 50 to 75 inches; that of the southern coast is from 30 to 40 inches; while in the eastern counties it is less than 25 inches. In some exceptional positions, such as Seathwaite in Cumberland, the average rainfall is upwards of 140 inches. In others, such as Hunstanton, in Norfolk, and some parts of Lincolnshire, it is little more than 20 inches; so that, in effect, there is on an average seven times as much rain in one part of England as there is in another. I am here speaking of an average of about twenty years, but in most places the annual variation is very great, the maximum annual fall being very much in excess of the minimum. Taking, for instance, the rainfall of 1852, and comparing it with that of 1854, I find that in Hertfordshire we we had in the former year rather more than 41 inches, and in the latter a little under 19 inches, or less than one-half; the average of forty years being about 27 inches. Of course, in estimating the water supply of any district, it is the minimum rainfall on which the engineer must base his calculations, and not the average.

Mr. G. J. Symons has carefully considered the limits of fluctuation in the total rainfall, and has arrived at the following conclusions, basing them upon the observations of a long series of years. In any part of this country:

1. The wettest year will have a rainfall of nearly half as much again as the mean.
2. The driest year will have one-third less than the mean.
3. The driest two consecutive years will each have one-quarter less than the mean.
4. The driest three consecutive years will each have one-fifth less than the mean.

At places, however, where the average rainfall is large, the extremes both of wetness and of dryness will be less pronounced than at those where the usual rainfall is small.

I have already mentioned the gradual increase of the rainfall in India as the slope of a mountain is ascended. It has, however, been assumed that, though in this country there is a gradual increase up to about 1,500 feet, yet, that above such an elevation it decreases. It has, indeed, been calculated that one-half of the vapor in the atmosphere is contained in the lowest 6,000 feet, and that at a height of 20,000 feet, there is only one-tenth of the moisture that there is near the surface of the earth, so that, at extreme elevations, there must be a diminution in the rainfall. Dr. Hann has well pointed out, "There must, on high mountains, be an upper limit of the maximum amount of rain. The decrease of temperature with increasing elevation involves a decrease in the amount of vapor held in the air. The maximum rainfall is, therefore, to be expected at the height at which, as a rule, condensation is first produced." As the usual height of *nimbi*, or rain-clouds, is in these latitudes not more than 1,500 feet, and as some of the observations in the Lake District seem to show a decrease above that level, the assumption just mentioned has been commonly accepted as true. Recent observations, however, in the Mountain Observatory on the summit of Ben Nevis, at an elevation of 4,406 feet, compared with those taken near the sea-level at Fort William, at the foot of the mountain, and at the lake, which is at a height of 1,840 feet above the sea, show that while at the lake the increase of the rainfall is about 30 per cent., it is at the summit fully 100 per cent.; in other words, twice as much rain falls on the top of Ben Nevis as at Fort William at the base of the mountain. It is, however, right to say that the observations on which this calculation is based extend over two seasons only, viz., the five months from June to October inclusive, in the years 1882 and 1883. During the other seven months of the year, so much snow falls at the top of the mountain, that exact measurement is impossible.

Our rivers and springs in this country are, as a rule, so little dependent upon the melting during the summer, of the snow that falls during the winter, that I need hardly do more than allude to the glaciers, which, in the case of many continental rivers, are during the summer months their main source of supply. With us, however, the rapid melting of snow is a frequent and principal cause of floods, especially in the case of districts consisting of porous soil, the surface of which has been hard-frozen before the snow fell upon it. Under ordinary circumstances, the gradual melting of snow makes it play much the same part as an equivalent amount of rain. At a rough estimate 12 inches, or 1 foot, of undrifted snow may be taken as an equal to 1 inch of rain.

Let us now consider what becomes of the rain, hail or snow after it falls upon the surface of the earth. With regard to the two latter forms in which water descends from the clouds, we may leave them as they lie, inasmuch as until they assume a liquid form they remain upon the surface of the ground and do not add to the water-supply, being, however, still liable to diminution from evaporation. As the rain, however, or the liquefied snow or hail, the future course which, under different conditions, it may have to follow, cannot at once be predicated. Although the utmost it can achieve is to remain undiminished in quantity, the falling rain in many respects resembles the good seed in the parable, though that which falls in stony places is, perhaps, that which produces the most abundant results. The amount and quality of the water-supply from a given amount of rain are, in fact, most immediately connected with the geological character of the country in which it happens to fall, through which it passes before being utilized.

If, for instance, we assume a tract of country to exist, consisting of bare, impervious, and unfissured rock, but the surface traversed by valleys all converging to one common outlet, it must be evident that the whole of the rain which falls upon it, less some small quantity carried off by evaporation, will, in a short space of time, be delivered by that outlet. If, instead of a complete valley system, there happen to be some depressed portions forming basins, apart from the valley system, the rain will accumulate in these, and there remain until carried off by evaporation; or, if the rainfall is in excess of the evaporation, the basins will gradually fill, until they arrive at a level at which they can overflow into some part of the valley system. In wet years this overflow may be nearly constant, in average years intermittent, and in dry years it may cease. Assuming again that these basins occupy the half of the area under consideration, it will be seen that while during some portions of a wet year nearly the whole of the rainfall would find its way into the outlet, during a dry year only one half of it would do so, the remainder being retained by the lake basins, and there evaporated.

If, instead of the rock being absolutely bare, there were a certain amount of superficial soil and vegetation upon it, the case would again be altered. Any moderate showers falling upon the area would be absorbed by the soil and the plants upon it, and but little would find its way to the outlet. A few days of fine weather would, in the summer months, when vegetation was in progress, suffice to render the superficial soil again dry and absorbent, so that practically during those months the water passing by the outlet might bear but a small proportion to the rain that fell. In the winter months, on the contrary, the proportion would be inordinately increased, and, even were the rock bare, it would be greater than in the summer, as the loss from surface evaporation would be less. In the case of the rocks being fissured, assuming them to be of an absolutely impervious kind, the result of the existence of fissures, provided they led down to no absorbent stratum, would not materially differ from the results of the presence of lake basins within the area, though the loss from evaporation would be less.

These are, of course, merely assumed cases, intended to show how variable may be the results of the same amount of rainfall under different conditions, although in some of our mountainous districts nearly analogous instances may be found. And it is principally in elevated tracts of country that hard and almost impervious rocks, like granites and gneiss, occur. In such tracts, the rainfall is usually great, and, as the amount lost by evaporation is nearly a constant quantity, the proportion of the rainfall which finds its way into the streams and rivers is large. In the Loch Katrine district, with a rainfall at the head of the loch of 103 inches in 1854, it has been calculated that 82 inches were discharged from the loch, showing a loss from evaporation and other causes of 21 inches.

The outflow from a district formed of heavy clay land will differ from that which results from rain falling on impervious rock, inasmuch as in dry seasons the clay becomes fissured by contraction to a considerable depth, and, though practically impervious, it is by no means unabsorbent. As a rule, too, in this country, such heavy lands are now artificially drained; and tracts of which, in old times, the surface became charged and soddened with water, that either discharged itself gradually, by natural channels, or was evaporated by the sun and wind, have now had their character modified to such an extent, that the rain which falls upon them is absorbed and delivered by the drains into the streams and rivers within a comparatively short time after it has fallen.

In old geological times, floods seem to have played a much more important part than they do at the present day, but they still cause great difficulties and dangers, with which the engineer has to contend. I need not, however, dwell upon these.

Both in clay districts and those formed of impermeable rocks, it frequently happens that there are superficial patches of drift gravels or sands. These being of an absorbent nature, are, after heavy rains, highly charged with water, some of which is subsequently delivered from them by gravity, at the lowest outfalls, forming what in some districts are called land springs. On permeable rocks, on the contrary, there are occasionally patches of impermeable clay, such as the Tertiary outliers which occur on the chalk; and these being again capped by permeable beds form small water-bearing basins. The position of villages on chalk hills is often due to the circumstance that a supply of surface water is thus made available. Indeed, as a rule, there are hydrogeological reasons for most sites of human occupation.

Although not entering into minute details, Mr. De Rance has given a hydrogeological map of England, which, for the general features of the country is extremely instructive. In it he has divided the character of the soil into four divisions: the impermeable; the partially porous; the "supra-pervious," or clays resting on permeable rocks; and the permeable. In comparing this with the Hyetographical map, it is at once seen how closely the areas of greatest rainfall correspond with those of the impermeable rocks. Nor is this to be wondered at, as these harder rocks have been better able to withstand the wear and tear of rain and rivers and the other denuding forces, and are, therefore, at a higher level and brought into closer contact with the water-yielding clouds than the districts of softer rocks at a lower level. Roughly speaking, the western parts of England and Wales consists of impermeable and partially porous rocks, and the eastern of the "supra-pervious" and the permeable, the area of the latter preponderating. Many of our river basins consist of rocks of two or more of these different kinds, and, in consequence, the flow and the character of the water in the rivers vary much from time to time. In wet weather many are subject to floods, owing to the water from impermeable and "supra-pervious" rocks being delivered into them. At such times their waters will be turbid, and probably contain less matter in solution than during dry weather, when they are mainly fed by springs rising out of the more pervious rocks, such as sandstone, limestone, and chalk.

The areas of the catchment basins of our rivers, and the extent and character of their flow, have of late years all been fairly well determined, and I need not enter into details concerning them. The streams and rivers form, as it were, parts of an extensive superficial drainage system, and the valleys through which they pass, though some are of old geological date, have in the main been excavated by the streams themselves, aided by the action of rain and frost.

To return to the history of the fallen rain. In addition to the supra-pervious beds, of which I must say a few words further on, a very large portion of England—and it is this part of the United Kingdom with which I believe we are here more particularly concerned—consists of more or less absorbent rock underlying a still more absorbent superficial soil, and it is to this fact that the comparatively permanent character of most of our rivers is due. It will be well, therefore, to consider in some detail the history of the rain falling upon such soils, from the time of its fall until it is well on its course to the sea. And for the present it will be best to leave aside any questions as to the proportion of it lost by evaporation and vegetation. Any moderate rain falling on an absorbent soil, whether plowed or covered with grass, at once disappears from the surface, and finds its way among the particles of the soil. In light soils, so universally is this the case, that even in heavy thunderstorms it is of rare occurrence that the water accumulates on the surface in such quantities as to run down the slope of a hill. As a consequence, in districts consisting of such soils, floods are almost unknown, and, when they do occur, are usually due to one of two causes. First, that the ordinary channels of the stream are insufficient to carry off the water delivered into them from the lanes, roads, and roofs of the district in which a heavy storm has fallen, for of course all these are unabsorbent; or, secondly, that the surface of the soil is hard frozen, and thus, as it were, waterproofed at the time of a heavy fall of rain, or a rapid thaw of snow.

The capacity of some soils or rocks for holding water in the interstices of their substance is great. In the case of the New Red Sandstone of Liverpool, Mr. Isaac Roberts found that it would absorb $\frac{1}{22}$ of its own weight of water, of which about one-half would not drain away, as it was held in the pores of the stone by capillary attraction. In loose sand and chalk, it has been stated that the absorption is from $\frac{1}{12}$ to $\frac{1}{9}$ of the weight, or at the rate of 2 gallons to the cubic foot. In oolites and limestones the proportion is less, but a cubic foot will still absorb from 10 to 14 pints of water. With continued rainfall anything in excess of what can be retained by capillary attraction gradually gravitates downwards until it arrives at a point where the rock is already charged with water. In the bottom of valleys with streams running along them, this saturated rock or soil will be met with near the surface, but the rain falling on hills may descend hundreds of feet before arriving at the point where its further progress is stopped by the spaces in the soil being already occupied with water, and then its effect is to add to the height of the already saturated portion. It will be asked, "What is it that keeps the bottom of the valleys charged with water, and prevents the water under the hills from finding some method of escape?" The answer is, friction. Could friction be removed, the surface of the saturated rock would present a nearly dead level, and the rain would escape at the lowest vent almost as quickly as it penetrated the ground. It is true that in most districts the absorbent rocks, such as sandstone, limestone and chalk, are underlain geologically by non-absorbent beds, such as clay, which prevent the rainfall from percolating to so low a level as that of the sea; but the inclination of the surface of the fully-saturated portion of the rock is quite independent of the underlying beds, and follows much the same laws when the pervious beds extend below the sea-level, and the natural vent for the surplus water is along the line of the sea shore, and not into any streams or rivers. At Brighton, for instance, the surface of the saturated portion of the chalk gradually slopes upwards as it recedes from the sea, this inclination being due to the frictional resistance offered by the pores and crevices in the chalk to its lateral passage. There is, however, a constant or nearly constant outflow from the chalk towards the sea; and though by the action of the tides the level of the outfall varies, the sea is never able to penetrate any distance into the chalk, and the rainfall in each year suffices to keep up an inclination sea-wards in the water-line or the surface of what has been termed the subterranean reservoir in the chalk. We can, however, imagine such a dearth of rain during many successive years that the plane of saturation would be level, or nearly so; and in that case, if by pumping from a deep well an artificial outlet for the subterranean water were formed below the sea-level, the salt water would, by gravity, find its way through the interstices in the chalk, and the water pumped would be brackish, or even salt. The same remarks which apply to springs discharging into the sea, will apply to those which find their outlet along the course of tidal rivers.

Turning now to an inland district, say also in the chalk, such as Hertfordshire, we find that it is intersected by valleys, into the origin of which I need not here enter, and that along the bottom of these there is a constant outpour of water from springs either along the beds of the stream or at their sides. By means of these the volume of the streams keeps gradually increasing as they flow; and, as they are found to be nearly independent of any immediate rainfall, it is evident that they are supplied from underground sources, and, in fact, are draining a subterranean reservoir of water among the crevices and interstices of the chalk. I shall speak of the upper surface of this reservoir as the water line, or as the plane of saturation, though it is not, properly speaking, a plane, but an uneven surface presenting valleys and elevations closely allied to the surface of the ground above it, though, so far as elevations are concerned, much less in degree. The extent to which friction impedes the passage of water through pervious rocks varies considerably even in chalk. It must, however, in all cases, be sufficient to retain the underground water at a slope fully as great as that of the streams running on the surfaces. In the middle chalk in Hertfordshire this slope is about 12 feet 6 inches to the mile, and near the outcrop in the lower portion of the white chalk, about 19 feet 6 inches. In some parts of Kent it is as much as 40 feet to the mile. It is evident, that could the water find its way along underground, with a less head than, say, 12 feet 6 inches to the mile, it would do so, and the streams would disappear. We can therefore assume that, even in comparatively dry seasons, the plane of saturation may be regarded as presenting much the same contours as the country itself would present were the hills planed away until their slope presented uniform gradients of about 13 feet to the mile. After heavy rainfalls, however, the water descending through the soil and arriving at this plane would gradually be piled up until the slope might be two or three times as much as this 13 feet to the mile; and in dry seasons the water thus piled up would, by the force of gravity, again subside and be delivered into the outlets along the bottoms of the valleys. The spring heads or sources of the streams would, owing to the accumulation of water from heavy rainfalls, be gradually driven higher up towards the heads of the valleys, so that the length of the streams might be increased by some miles. This is no fancied case, for I have known the source of the little river Ver to be at least five miles farther up the valley in one year than in another; and I have known the depth of water in a well at a considerable distance from a stream to vary as much as 70 feet in two consecutive years.

One can indeed imagine such a continued fall of rain that the whole body of the hills would become saturated with water, and the plane of saturation correspond with the configuration of the land surface. In such a case the wells would be full to the brim, as where there is no great draught upon them the level of the water in wells shows the position of the water line or plane of saturation. Where the pumping from a well in a porous rock is excessive, the level of the water in it is reduced below that of this plane, and an inverted cone of depression is formed in the plane of saturation, the angle of which is determined by the amount of friction in the rock.

Of course, the inclination of the plane towards the bottom of the valleys in which the water escapes is constantly varying. If the rainfall which finds its way into the ground is in excess of the water escaping by the springs, the angle of the plane becomes greater. If, on the contrary, the escape by the springs is greater than the absorbed rain, the angle is reduced. It is this circumstance which accounts for the intermittent streams which are commonly known as "bournes." These are usually situated in transverse valleys, running into some main valley in which there is a stream. Assuming that the inclination of such transverse valley is 20 feet to the mile, it is evident that so long as the inclination of the plane of saturation is at a less gradient, no water will be visible above ground; but so soon as the 20 feet is exceeded in consequence of a wet season, the bottom of the valley intersects the plane of saturation, and it becomes the course of a stream which continues to run until the angle of the plane of saturation again becomes less than that of 20 feet to the mile. When the bottom of the valley is uneven, and the slope of the plane of saturation nearly corresponds with the mean of that of the valley, the phenomenon is seen of a watercourse running at intervals along the bottom of the valley, the water finding its way underground where there are prominences in the land surface.

Although the whole of the chalk below the plane of saturation is full of water, and more or less pervious in every direction, yet as the surface of the plane descends, the water, in escaping into the valleys, follows certain lines of least resistance, and thus in many places gives rise to springs sometimes of great volume.

In the upper portion of the chalk there are usually layers of nodules of flint, extending over large areas and occurring at intervals of 3 or 4 feet, the one over the other. Among these flints the underground water seems often to find its way more readily than through the interstices and crevices in the chalk itself; so that, in boring, an accession of water is obtained directly a layer of flint is traversed. So readily do these waterways communicate with the stores of water at a higher level, that the water in a deep boring in the bottom of a valley will rise higher than the level of the stream running through it, and overflow into its course.

From deep borings the water generally rises at a higher temperature than from ordinary springs. The water from the well-known artesian well at Grenelle, close to Paris, has a temperature of 82° Fahrenheit, and comes from a depth of rather more than 1,800 feet. This temperature is about 30° above that of the springs of the districts, showing an increase of about 1° for every 60 feet of the descent. At the bottom of the deep boring lately made at Richmond, 1,334 feet from the surface, the water has been found to have a temperature of 75½° Fahrenheit, from which an increase in heat of 1° to every 53 feet in depth has been deduced. This increase in temperature in descending from the surface seems universal, though varying in degree in different localities; and it seems probable that in most cases the heat of thermal spings is due to the fact that the channels through which the water has to pass between the time when it is received into the ground at one place, and that at which it reappears at another, descend to a great depth from the surface.

But, to return to the chalk. Where this rock is overlain by stiff clay, through which, however, it in places penetrates, what are known as swallow-holes are formed, and the rain, falling on tracts of impervious clay, forms streams, which find their way to such swallow-holes and disappear in the chalk. In such cases, it seems probable that by the continual delivery of large bodies of water into one place, the lines of least resistance in the chalk have been widened out by combined mechanical and chemical action, so that subterranean watercourses are formed. The caverns, which occur in so many limestone districts, often owe their origin to nearly similar causes.

It not unfrequently happens that pervious strata lie between others of an impervious character, forming, as it were, a porous basin placed between two other basins. In such cases the pervious beds become saturated with water, and the excess of the rainfall finds its way towards the sea over the exposed portion of the beds. A boring made through the upper impervious basin will tap these water-bearing beds, and, if the exposed portion is at a higher level, the water will probably rise to the surface, or even higher, and form a true artesian well. Of course, any water taken from this well will eventually affect the plane of saturation at the exposed portion of the beds, and, assuming that there is no disturbing element, the flow of the streams over them will be diminished to the extent of the water taken from the well. In some cases, the naturally pervious beds beneath the impervious are so much consolidated by their weight, that the free passage of water through them is impeded, and though at first the artesian wells yield an abundant supply, it gradually diminishes, and pumping has to be resorted to, so that eventually a cone of depression is formed around the wells. I need hardly do more than mention the deep wells in the chalk under London as an instance of this phenomenon.

I have hitherto been speaking of the rainfall as if the whole of it that sank below the surface found its way to the saturated portion of the pervious rocks. This, however, is far, very far indeed, from being the case. During the summer months the amount of the rainfall carried off by evaporation, and by the vegetation which is going on all over the surface of the ground, is very large, often fully as great as the rainfall; and even during the winter, unless the rainfall has been continuous, it penetrates but a little way into the ground, and does not get beyond the reach of the evaporating power of the sun and the air. We have only to turn over a few spadefuls of earth to see how small a distance even a heavy shower penetrates a dry soil.

The first to make experiments on the subject of the proportion of percolation through about 3 feet of soil to the rainfall on the surface were Dr. John Dalton, of Manchester, and M. Maurice, of Geneva, about the end of the last century. Since that time numerous experiments have been conducted by various observers, both here and abroad. The principle on which they have been carried on is much the same in all cases. An impervious vessel, open at the top, is sunk in the ground, so that the sides, which are brought to a knife-edge, barely protrude above the surface. It is then filled with soil of the character on which it is proposed to experiment, and the surface is either left bare or clothed with vegetation. From the bottom of the vessel a pipe conveys any water that penetrates so far from the surface into a suitable receiver. This is carefully measured, and its volume compared with that of the rain falling on the surface as ascertained by an ordinary gauge. It has generally been supposed that water which has descended 3 feet from the surface of the ground is beyond the influences of evaporation and vegetation. Capillary attraction seems, however, capable of bringing up water from a greater depth; and the roots of some plants will find their way farther than 3 feet, as will also worms. The difference, however, between the quantity of water which out of a given rainfall descends 3 feet and that which descends 5 feet is not large. The results of many experiments on percolation have been recorded in the Proceedings of this Institution, and those of Mr. Charles Greaves and of Sir J. B. Lawes and Dr. Gilbert are especially worthy of notice. In the latter case the gauges, instead of being artificially filled with soil, were constructed round blocks of the natural soil with a surface area of $\frac{1}{1000}$ part of an acre, and a depth of 20, 40, and 60 inches respectively. The surface of these plots was kept free from vegetation by being occasionally hoed, and the following were the results for the ten years 1871 to 1880. Out of a mean rainfall of 31.451 inches, 14.040 passed through 20 inches of soil, and 13.241 through 60 inches; or, dividing the years into summer and winter periods of April to September, and October to March, it appears that out of 16.365 inches of summer rain only 4.111 found its way through 60 inches of soil, while in the winter there passed 9.130 inches out of a rainfall of 15.086 inches.

I think that I may claim for my uncle, the late Mr. John Dickinson, the honor of being the first in this country to repeat the experiments of Dr. Dalton. His observations began in 1836; but new gauges, formed of cast-iron, were fixed at Nash Mills in 1853, and have been in continuous operation ever since under my own directions. One of the receivers is filled with the surface soil of the district, as nearly as possible as it occurs in nature, and the other with broken chalk, the surface in each case being covered by growing grass. I do not say that the experiments are so fully carried out as those of Mr. Greaves and Dr. Gilbert and Sir J. B. Lawes, inasmuch as the receivers are smaller, and the soil artificially introduced; but they have the merit of being continuous, and in their general results they are corroborated by the observations of others. I have, therefore, arranged the results of thirty years' observations in a diagrammatic form.

The average of the thirty years shows that out of a total rainfall of 27.843 inches, 6 519 passed through 3 feet of soil and 10.650 through the same depth of chalk.

Out of the winter rainfall of 13.752 inches the percolation was 5.707 inches and 8.532 inches; but out of the summer rainfall, when vegetation was in progress and evaporation greater, the amounts are 0.812 and 2.118 respectively out of a rainfall of 14.091 inches. The variations in the proportion of the percolation to the rainfall are very great, even in the winter half-year, so much depending upon the manner in which the rain falls, and whether it is constant for some days or intermittent. I will not detain you with figures, but will give one or two instances of maxima and minima. In the winter of 1879-80 only 5.84 inches of rain fell, of which 2.79 entered the soil to a depth of 3 feet, while in the winter of 1870-1, with a fall of 12.54 inches, only 0.208 percolated.

In the winter of 1882-3, no less than 22.67 inches fell, with a percolation through 3 feet of soil of 11.67 inches, and in that of 1880 81, 13.59 inches percolated out of 20.07 inches. In the summer of 1870 only 7.59 inches fell, and none percolated; whereas, in the summer of 1879, 25.09 inches of rain fell, and 6.94 inches percolated.

With a fall of 11.69 inches in the winter of 1874-5, 4.15 inches percolated; whereas, 9.64 inches in 1858-9 gave only 0.09 inch. In the summer of 1859, 18.09 inches gave no percolation, and in that of 1870, 18 46 inches gave 2.16 inches.

It cannot be too often insisted on that, in the case of water-supply derived from porous soils, it is in the highest degree illusive to depend upon averages. The minimum, or at the best, the lowest average of three successive years, is the utmost on which we can rely. Taking the triennial period 1862-4, we find that, with a rainfall of about 22 inches, only $3\frac{1}{2}$ inches percolated to a depth of 3 feet in the soil; and from 1869 to 1871, out of 25 inches, little more than 4 inches. The percolation through chalk is greater, but in the first period mentioned the average in the three years was only 5.20 inches.

Nor can it be too often repeated, that every gallon of water pumped and carried away from an absorbent district is so much abstracted from the flow of the streams of that district. There are, of course, some tracts of country—as for instance, on our own southern coasts—in which there are no surface streams, and the natural vent for the underground water is by springs along the sea-shore; but in inland districts the streams form an exact gauge of the excess of the rainfall over the water carried off by the processes of evaporation and vegetation. The streams being merely the overflows from the subterranean reservoir, it is evident that any artificial diminution of the water in the reservoir must, *pro tanto*, affect the streams; and even in those districts where the discharge is towards the sea, that discharge will be diminished in a similar manner. I have heard people speak of vast and inexhaustible stores of water, which have been laid up in the body of the earth for untold ages, and which have merely to be tapped to meet all the necessities of a crowded population; and I have heard others speak of springs as if there were some spontaneous process in nature by which water was produced in unlimited quantities. But all here will readily acknowledge that the water that is upon the earth beneath, and the water that is under the earth, derives its existence from no other source than from the heaven above.

Mr. J. T. Harrison's scheme for obtaining water by means of tunnels in the chalk of the Thames valley merely means that all the water derived from the tunnels will either be intercepted on its way to the river, or filter into the tunnels from the bed of the river itself. The flow of the Thames below will be diminished by just the same amount of water as that abstracted by means of the tunnels.

I have, however, dwelt almost too long on this part of my subject, and will only add that an annual supply of 4 inches of rain will, from every square mile of country, give a daily quantity of nearly 160,000 gallons of water, which, at the rate of 32 gallons per head per diem, would suffice for a population of five thousand souls. A population of four millions, such as that of the metropolitan area, would, therefore, if supplied from deep wells in the chalk, as some have gravely recommended, absorb the total water-supply of 800 square miles of country, or of an area one quarter larger than the county of Hertford, and the whole of the surface-streams over this large area would in dry years absolutely disappear.

I have already mentioned the fact that in many districts, especially those consisting of calcareous rocks, the underground waters have a tendency to form channels through which they pass, in order, eventually, to appear at the surface in the form of springs. The formation of these channels seems in part due to the power of water to dissolve the lime-stone rock through which it passes. Pure water, indeed, possesses but small solvent powers; but when it is charged with carbonic acid, which rain-water derives both from the atmosphere and from decaying vegetable matter in the soil its powers are largely increased, and, as a consequence, the spring and well water in such districts is largely charged with carbonate of lime. In other districts sulphates and chlorides are often dissolved, sometimes to such an extent as to render the waters medicinal or quite saline in character and unfit for ordinary use. These chemical impurities impart to the water containing them the quality of hardness, which the waters flowing off the surface possess in a far less degree. These latter, however, are liable to hold a larger proportion of organic and vegetable matter either in suspension or in solution, and, on the whole, deep well water is probably the more palatable.

It is hardly within my province to speak about the processes which have been introduced for the artificial softening and purification of water, but I may mention the natural agents which to some extent produce these effects. Where, for instance, a wide and shallow lake intervenes in the course of a river, it will often be found that the water passing out is softer than that which enters the lake, some of the salts of lime which were held in solution having been deposited or absorbed by the vegetation in the lake. Weeds and fishes, although when dead they are sources of impurity, yet when living are great purifiers of water, as it is on the impurities that they subsist. It would indeed be difficult for animal or vegetable life to be maintained in chemically pure water. The exposure of water to the action of air in its course down a river, especially where there are rapids and falls, has a great effect in the decomposition and removal of nitrogenous impurities. These, however, are subjects which will probably be dealt with by my friend Dr. Pole in the next lecture.

As an introduction to what has to follow, I have attempted to give you some slight outline of the natural laws which regulate the circulation of water from the sea through the air to the earth, until it again returns to the ocean. For details there are numerous authorities which may be consulted, such as the various Reports of the Rivers Pollution Commissioners, Mr. De Rance's "Water Supply of England," Mr. G. J. Symons' publications, and those of Professors Prestwich and Tyndall, Mr. Beardmore, Mr. Bateman, and others.

The principal points which, it appears to me, the engineer should always bear in mind are these:

1. That the higher the level and the nearer the sea, especially on our western coasts, the greater is the rainfall.

2. That in these high districts the rocks are, as a rule, more impermeable than in the low, and the supplies to the streams larger and more immediate.

3. That in the low-lying and eastern districts the rainfall is small, and the rocks for the most part absorbent.

4. That while providing means for receiving and dealing with the maximum amount of supply, reliance can only be placed on the minimum, and not on the average.

5. That though in the case of permeable soils the absolute minimum of percolation may be disregarded, yet that the average of three years seems to show that not more than 4 or 5 inches of the annual rainfall can safely be regarded as available for the supply of both the wells and rivers of the district.

6. That any water abstracted from wells in a permeable district is so much abstracted from the sources of the neighboring streams, though in many cases it can be and is returned to them after use.

In addition, I may venture to suggest that while at no town in this kingdom would there probably be much difficulty in obtaining a supply of practically pure water sufficient for drinking and cooking purposes, there exists no physical necessity for watering the roads or flushing the sewers with water of the same pure quality.

My mission this evening does not, however, extend to questions of water-supply. It has been my task briefly to trace what may be termed the natural history of our springs and rivers, and I must leave the subject of how best to utilize their waters in the competent hands of those who are to follow me in this course of lectures.

THE RESISTANCE OF BUILDING MATERIALS TO FROST.

From "The Builder."

This subject has from time to time engaged the careful attention of scientific men, and amongst others, Brard, Braun, and Tetmajer have published in various Continental journals (as well as in special treatises) the results of their detailed investigations. Brard's test consists in the saturation of the material to be tested with a solution of glauber or other salt of a given strength, and in then permitting the expulsion of the salt by crystallization, it being supposed that the salt would produce an effect similar to that of the congelation of water. Braun institutes a comparison between the strength of extension of the material and the force of the solidifying water, assuming that a material is not capable of resisting frost when the former is less than the latter. Tetmajer employs a number, expressing the proportion between the resistance to pressure in a dry and in a wet state. In addition to the above, Hempel's test with muriatic acid deserves mention.

In reviewing these processes, Herr A. Blümcke points out in the *Thonindustrie Zeitung* that all of them subject the material to conditions which are not to be found in practice, while their more or less complicated nature forms an obstacle to their adoption. On the other hand, the process of Bauschinger is more practical, consisting in the exposure of the material twenty-five times to frost in the open air, the strength before and after the test serving as a guide to the resisting power. The production, by artificial means, of the needful degree of cold suggests itself, but hitherto this process has only been accomplished by the aid of chemicals, which affect the substances treated in such a way as to prevent the ready appreciation of the effects produced by frost. Hence, a proposal of Hericat de Thury has been carefully studied by Herr Blümcke, with the result of his perfecting the following method:

The stones to be tested are placed, two at a time, in a wire framework suspended from a rod. These are placed in a cylindrical metal vessel, sloped off at the foot in funnel form, and with a cover. This is inclosed in a larger vessel of the same shape, and held in position by supports. There is a space of 2 inches around the smaller vessel, which space is filled with a refrigerating mixture. A vessel, 2 inches in height, is also placed above, filled with the same mixture. At one time an escape-pipe had been in use at the lower part of the apparatus, but it was found more practicable to empty it after each operation by a siphon. The cold mixture used consists of three parts of ice in small pieces and one part of powdered rock salt, its cheapness being a considerable advantage. The lowest temperature obtained in the interior of the apparatus was below 10° Fahrenheit, although a still lower temperature could have been arrived at. Small thermometers were inserted in the stones, and although two hours sufficed to bring these to the temperature of the surrounding air, the stones were subjected to the process during a period of three hours. Felt or sawdust was used to procure isolation from the outer air, the former being more effectual, but the latter preferable on account of its cheapness.

In the selection of the stones, as well as in the general conduct of the experiments, Herr Blümcke had the advantage of the advice of Professor Gottgetreu, the trials being conducted in the laboratory of Professor Von Beetz. The stones were in cube form, the length of the sides being about $3\frac{1}{4}$ inches, and the surfaces roughly dressed. Two specimens were tested in each case, and one of them was completely saturated with distilled water. Boiling was, however, avoided, so as not to expose the material to a degree of heat which it is not in practice called to endure. When a material is very porous it is impossible to freeze it when thoroughly saturated. After removal from the refrigerating apparatus the cubes were placed in a small trough, covered with water, and left there three hours, so as to again be brought to the temperature of the room. When taken out the stones were covered with a coating of hoar frost, and if then left for some time in water a loosening of small particles was perceptible in the portions not capable of resisting frost. Before the next subjection of the stones to the refrigerating process the surfaces were gently rubbed with a feather. Herr Blümcke repeated the process until distinct traces of injury were visible, such as cracks, peeling, loosening of corners, &c. If a stone had been ten times subjected to the frost, with such traces appearing, the quantity of the mass separated after the evaporation of the water was ascertained, and the process continued until destruction commenced. A second cube was subjected to a stream of water during one hour upon three sides. In this case there was no attempt made to ascertain the loss of volume, but the application of the water was continued until injury became apparent. These external appearances were quite the same as if the stone had been saturated, but were considerably later in manifesting themselves.

From these experiments Herr Blümcke has deduced the theory that a material has higher properties of resistance to frost, according to the restriction of the loss in weight, caused by the repeated application of the freezing process. In trials made upon sandstone the following results were obtained. In all cases cracks were finally visible which ran close to each other (parallel to one or several edges), and produced crumbling when the operations were persevered with.

Name.	Specific gravity.	Water taken up in per cent. of volume.	Number of freezings.	Loss in weight. Grammes.
1. White, Langenzenn	1.97	22.6	2	5.0088
2. Green, Ellingen	2.00	24.1	3	0.7446
3. Grey, Oberdachstetten	2.06	21.1	3	0.5910
4. Yellow, Lengast	1.83	32.6	3	0.4562
5. Red and white striped, Waldaschaff.	2.22	11.0	3	0.4067
6. Green sandstone, Albech	2.14	18.1	4	0.2835
7. Yellow, origin unknown	2.34	14.6	6	0.2541
8. Yellow, Zeil	2.18	13.9	8	0.1058
9. Grey, Gründen	2.44	13 7	13	0.0835
10. Red, Rothenfels, A. M	2.31	11.3	24	0.0820

Large pieces were detached from No. 1, and cracks appeared all over Nos. 2 and 3. On No. 4 there were two kinds of coatings, a darker one, which broke off more than the other, and a lighter one, which showed cracks. Nos. 6 and 8 peeled on the surface, and No. 7 was much cracked. After the thirteenth freezing of the ninth type a splinter became detached from one corner, but cracks parallel to the edge were not visible till after the forty-third freezing.

By proceeding in this way it is not necessary to wait for the visible destruction of the material. Coupled with the definition of the degree of resistance to frost is an approximate estimate of the period a stone will last, as it is not difficult to arrive at the number of alternations during an average winter between frost and thaw. When thoroughly saturated stones are tested, the results are applicable to the most unfavorable circumstances, and are consequently the more reliable. Should a material not show injury at the temperature applied, this fact does not establish its power of resisting frost, but renders advisable the trial of a still lower temperature; in no case, however, below the range to which, in practice, the stone would be subjected. Finally, Herr Blümcke does not claim that he has solved all the questions connected with this interesting subject, but considers that his illustration of what may be done with simple means, by skillful and capable hands, may not be devoid of value to the cause of science.

COMPARATIVE EXPERIMENTS ON THE WELDING OF STEEL AND WROUGHT IRON.

By J. BAUSCHINGER.

These experiments were undertaken by the author at the instance of an engineering firm.

Similar experiments had been previously made at the Royal Mechanical-Technical Experimental Institute at Berlin, and by Mr. W. Hupfeld, at Prevali, which gave very different results; those at Berlin being very unfavorable, those at Prevali very favorable, as regards the welding capacity of steel (*Flusseisen*). The author recapitulates the main results of these tests before describing those made by himself. The materials used in the latter were steel (*Flusseisen*), from the "Peine" ironworks at Hanover, and bar iron of various sections from the "Neuhoffnungshuette," near Herbauer, in Nassau.

The test-pieces were flat, square, and round in section, the largest being 80 × 30 millimeters (3.149 × 1.181 inch). Each piece was cut in two cold, swelled up on the anvil when hot 5 to 10 millimeters (0.196 to 0.392 inch), and, after heating to the proper degree, the two portions were laid on each other, and welded together by hand or steam hammer.

Some preliminary studies were made in the laboratory of the college to ascertain the best method of welding, and the best flux for steel; quartz sand answered the latter purpose, while it was found that a rather less degree of heat was required for steel than for wrought iron; a pure coal fire was used.

In the chief experiments the steam hammer was employed. Every piece, after welding, was tested in the usual way for tensile strength; the limit of elasticity, contraction, extension, and ultimate strength being determined, the same quantities having been measured for pieces of exactly similar quality, section, and length, but without a weld.

The results are given in a tabular form. Both for steel and iron the limit of elasticity is nearly always reduced by welding, and this is, without exception, the case as regards the extension, the contraction of welded is less than that of unwelded pieces when the fracture takes place in the welded portion.

The general conclusions arrived at are, that for steel the best welding temperature is just at the transition from a red to a white heat; a quick fire and smart handling are necessary, as the piece should not be long in the fire.

Analyses were made of three samples, one of which welded admirably, the second badly, and the third not at all.

The author is of opinion that, in the case of mild steels, such as those tested, with a low carbon, intended to take the place of bar iron, success, or otherwise, in welding, depends less on the chemical composition than on the mechanical treatment.—*Abstract of Inst. of Civil Engineers.*

IMPROVEMENTS IN THE ARRANGEMENT AND RATING OF CURRENT-METERS, AND IN THE METHOD OF CALCULATING DISCHARGES.

By CHARLES RITTER.

From "Annales des Ponts et Chaussées," for Institution of Civil Engineers.

A DETAILED account is given by the author of the elaborate investigations which he conducted, with the object of rendering more serviceable the two gauging instrument generally employed in France, namely, Darcy's gauge-tube, and Woltmann's current-meter as improved by Mr. Baumgarten; for the purpose of facilitating the rating of these instruments; and lastly, for improving the methods of calculating the discharge from the indications furnished by the instruments. The ordinary type of gauge-tube is awkward to handle; and gauging with a current-meter which has to be drawn up out of the water for each reading is a slow process, especially at great depths. Moreover, the rating of these instruments has hitherto been frequently so difficult, slow, and costly, that either the rating has been dispensed with, thus introducing an uncertainty in the results, or the most favorable time for gauging has slipped by during the preliminary operations.

The gauge-tube adopted has the pressure-gauge distinct from the nozzles, which are connected together by india-rubber tubes. The rod carrying the nozzles is thereby made much more handy, whilst the observer can suspend the pressure-gauge so as to keep the summits of the two columns of water always in view, whose oscillations are considerably reduced by means of a regulator interposed between each india-rubber tube and the gauge. The nozzle pointing towards the stream has not been altered in type, but its best form consists of a straight tube 0.2 inch in diameter, and 4 to 6 inches long, tapered at the extremity, and presenting a cylindrical orifice of 0.08 inch in diameter throughout the tapered portion. The side nozzle, however, has been replaced by a statical mouthpiece, which indicates the pressure corresponding to the surface-level of the current without needing any correction. The mouthpiece adopted for this purpose consists of a tube, 4 inches long and 0.4 inch in diameter, open at both ends, and having a lateral orifice in the middle, from 0.04 to 0.08 inch in diameter, round which the second connecting-tube is soldered. Each connecting-tube consists of two portions, one portion, a rigid copper tube, and the other, a flexible india-rubber tube. The copper tubes carry the nozzles at their lower extremities, and have an air-chamber at their upper ends, with a stop-cock at the top. Each air-chamber communicates with one of the india-rubber tubes by a lateral opening. The air-chambers receive the bubbles of air, either introduced by accidents in the manipulation or contained in the water itself. The stop-cocks serve for adjusting the instrument. The copper tubes should not be less than about $\frac{1}{4}$ inch diameter, to allow of the ready passage of air-bubbles into the air-chambers. The india-rubber tubes are made about $\frac{1}{6}$ inch internal diameter, for though they are little liable to receive air-bubbles, a very small diameter would impede the establishment of an equilibrium in the pressure-gauge. Their external diameter is made 0.4 inch, so that they may be bent without collapsing, which would impede the flow. The two connecting-tubes are enclosed in a hollow rod, 1 inch in diameter, which is provided with a vane at the bottom to facilitate the adjustment of the line of the nozzles. The pressure-gauge is furnished with a third tube to facilitate certain operations of rating. By the adoption of the statical mouthpiece, no rating is required, for the difference in the height of the two columns of water in the pressure-gauge h, is equal to $\frac{V^2}{2g}$, without any coefficient being required in the equation. Also the coefficient of gauge-tubes with any other side mouthpieces can be easily determined by connecting the mouthpiece with the third tube of the pressure-gauge and observing the heights of the three columns of water in different points of the stream. The most convenient instrument of the type described has a total length of $6\frac{1}{2}$ feet, and is not suitable for depths exceeding $3\frac{1}{2}$ feet; but by screwing on a lengthening piece to the rod it can be used for depths of 5 to 6 feet. This type of instrument is not suitable for considerable depths, both on account of the difficulty of handling an apparatus of over 10 feet in length when raised out of water, and also owing to the escape of air-bubbles when the pressure is reduced in the tubes by immersion, necessitating constant readjustments. These difficulties, however, might be obviated by using a different gauge-tube for each separate group of depths comprised within intervals of 5 feet.

The current-meter adopted has four spiral vanes, and is provided with an electrical recorder for every fifty revolutions. It is inclosed within a hollow copper cylinder, 8 inches long, open at both ends, having a diameter of about $4\frac{1}{2}$ inches, just large enough not to interfere with the revolution of the vanes. The cylinder protects the current-meter from the disturbing influences of oblique currents, and it facilitates the free suspension of the instrument which is directed in the line of the current by a large flat plate behind. The instrument is suspended in small depths, or near the surface by a hollow copper rod; but in greater depths, when the length of rod necessary would be inconvenient, it is hung from a cord formed of two insulated copper wires, which convey the electrical current. The current-meter is kept in position by a second cord (kept tight by a weight at the bottom of the river, and a winch above) down which it descends, being guided by rollers. The rating, besides being conducted in the usual manner by drawing the meter through still water, was effected, for small velocities, by forming a very regular artificial current; and it was also obtained in the river itself, during the experiments, by placing the front nozzle of a gauge-tube in front of the axis of the current-meter and comparing the results of the two methods. When the velocity of a current is very small, the eddies produce almost as much effect as the direct current, so that the action of the vanes of the meter is uncertain; and consequently, it is unadvisable to employ the current-meter for gauging currents having velocities under 1 to $1\frac{1}{3}$ foot per second.

Owing to the variations and irregularities in the current, the velocities given by the instruments are always greater than the direct motion of the stream.

Sometimes, also, under exceptional circumstances, the recorded velocities are too low. Accordingly, in order to make allowance for these discrepancies between the real and calculated results, the mean of two-thirds of the largest velocities, and the mean of two-thirds of the least velocities are taken, and half the sum of these two means is accepted as the actual mean velocity in the section. The mean velocities throughout the whole section can be obtained by tracing the lines of equal velocity, as gathered from the observations, and prolonging these lines, in accordance with the indications furnished by the adjacent lines, to those parts of the section which cannot be reached by the instruments. The article concludes with some practical applications of the above methods of gauging, in illustration of the processes adopted and the degree of accuracy attained.

THE LUMINIFEROUS ÆTHER.

By DE VOLSON WOOD, C. E., M. A.

From the "Philosophical Magazine."

Two properties of the luminiferous æther appear to be known and measurable with a high degree of accuracy. One is its ability to transmit light at the rate of 186,300 miles per second,* and the other its ability to transmit from the sun to the earth a definite amount of heat energy.

In regard to the latter, Herschel found, from a series of experiments, that the direct heat of the sun, received on a body at the earth capable of absorbing and retaining it, is competent to melt an inch in thickness of ice every two hours and thirteen minutes. This is equivalent to nearly 71 foot-pounds of energy per second.

In 1838 M. Pouillet found that the heat energy transmitted from the sun to the earth would, if none were absorbed by our atmosphere, raise 1.76 grammes of water 1° C. in one minute on each square centimeter of the earth normally exposed to the rays of the sun.†

This is equivalent to 83.5 foot-pounds of energy per second, and is the value used by Sir William Thomson in determining the probable density of the æther.‡ Later determinations of the value of the solar constant by MM. Soret, Crova, and Violle have made it as high as 2.2 to 2.5 calories. But the most recent, as well as the most reliable, determination is by Professor S. P. Langley, who brought to his service the most refined apparatus yet used for this purpose, and secured his data under favorable conditions; from which the value is found to be 2 8 ± calories * with some uncertainty still remaining in regard to the first figure of the decimal. We will consider it as exactly 2.8 in this analysis, according to which, there being 7,000 grains in a pound and 15.432 grains in a gramme, we have for the equivalent energy

$$\frac{2.8\times15.432}{7,000}\times\frac{9}{5}\times\frac{772\times144}{0.155\times60}=$$
133 foot-pounds

per second for each square foot of surface normally exposed to the sun's rays, which value we will use. Beyond these facts, no progress can be made without an assumption. Computations have been made of the density, and also of the elasticity, of the æther founded on the most arbitrary, and in some cases the most extravagant, hypotheses. Thus, Herschel estimated the stress (elasticity) to exceed

$$17\times10^9=(17,000,000,000) \text{ pounds per square inch};\dagger$$

and this high authority has doubtless caused it to be widely accepted as approximately correct. But his analysis was founded upon the *assumption* that

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* Professor Michelson found the velocity of light to be 289,740 meters per second in air, and 299,828 meters in a vacuum, giving an index of refraction of 1,000,265. "Journal of Arts and Science," 1879, vol. xviii., p. 390.

† *Comptes Rendus*, 1838, tom. vii. pp. 24-26.

‡ "Trans. Roy. Soc. of Edinburgh," vol. xxi. part 1.

* *Am. Journ. of Arts and Science*, March, 1883, p. 195. Also *Comptes Rendus*.

† "Familiar Lectures," p. 282.

the density of the æther was the same as that of air at sea level, which is not only arbitrary, but so contrary to what we should expect from its non-resisting qualities, as to leave his conclusion of no value. That author also erred in assuming that the tensions of gases were as the wave-velocities in each, instead of the mean square of the velocity of the molecules of a self-agitated gas; but this is unimportant, as it happens to be a matter of quality rather than of quantity. Herschel adds, "Considered according to any hypothesis, it is impossible to escape the conclusion that the æther is under great stress." We hope to show that this conclusion is not warranted; that a great stress necessitates a great density; but that both may be exceedingly small. A great density of the æther not only presents great physical difficulties, but, as we hope to show, is inconsistent with the uniform elasticity and density of the æther which it is believed to possess; and every consideration would lead one to accept the lowest density consistent with those qualities which would enable it to perform functions producing known results.

In a work on the "Physics of Æther," by S. Tolver Preston, it is estimated that the probable inferior limit of the tension of the æther is 500 tons per square inch, a very small value compared with that of Herschel's. But the hypothesis upon which this author founded his analysis was—The tension of the æther exceeds the force necessary to separate the atoms of oxygen and hydrogen in a molecule of water; as if the atoms were forced together by the pressure of the æther, as two Magdeburg hemispheres are forced together by the external air when there is a vacuum between them. This assumption is also gratuitous, and is rejected for want of a rational foundation.

Young remarks: "The luminiferous æther pervading all space is not only highly elastic, but absolutely solid."* We are not certain in what sense this author considered it as solid; but if it be in the sense that the particles retain their relative positions, and do not perform excursions as they do in liquids, it is a mere hypothesis, which may or may not have a real existence. If it be in the sense that the particles suffer less resistance to a transverse than to a longitudinal movement, there are some grounds for the statement, as shown in circularly-polarized light. Bars of solids are more easily twisted than elongated, and, generally, the shearing resistance is less than for a direct stress. It certainly cannot be claimed that the compressibility of the æther (in case we could capture a quantity of it) is less than that of solids.

Sir William Thomson made a more plausible hypothesis, by assuming that "the maximum displacement of the molecules of the æther in the transmission of heat energy was $\frac{1}{50}$ of a wave length of light, the average of which may be taken as $\frac{1}{50000}$ of an inch." Hence the displacement was assumed to be $\frac{1}{2500000}$ of an inch; by means of which he found the weight of a cubic foot to be $\frac{2}{3}\times10^{-20}$ of a pound.* We also notice that one Belli estimated the density of the æther to be $\frac{1}{2}\times10^{-13}$ of a pound; † but M. Herwitz, assuming this value to be too small and Thomson's as too large, arbitrarily assumed it as 10^{-18} of a pound per cubic foot; but arbitrary values are of small account unless checked by actual results.

We propose to treat the æther as if it conformed to the Kinetic Theory of Gases, and determine its several properties on the conditions that it shall transmit a wave with the velocity of 186,300 miles per second, and also transmit 133 foot-pounds of energy per second per square foot. This is equivalent to considering it as gaseous in its nature, and at once compels us to consider it as molecular; and, indeed, it is difficult to conceive of a medium transmitting light and energy without being molecular. The Electromagnetic Theory of Light suggested by Maxwell, as well as the views of Newton, Thomson, Herschel, Preston, and others, are all in keeping with the molecular hypothesis. If the properties which we find by this analysis are not those of the æther, we shall at least have determined the properties of a substance which might be substituted for the æther, and secure the two results already named. It may be asked, Can the Kinetic theory, which is applicable to gases in which

* "Young's Works," vol. i. p. 415.

* *Phil. Mag.*, 1855 [4] ix. p. 39.

† Cf. *Fortschritte der Physik*, 1859.

waves are propagated by a to-and-fro motion of the particles, be applicable to a medium in which the particles have a transverse movement, whether rectilinear, circular, elliptical, or irregular? In favor of such an application, it may be stated that the general formulæ of analysis by which wave motion in general, and refraction, reflection, and polarization in particular, are discussed, are fundamentally the same; and in the establishment of the equations the only hypothesis in regard to the path of a particle is—It will move along the path of least resistance. The expression $V^2 \propto e \div \delta$ is generally true for all elastic media, regardless of the path of the individual molecules. Indeed, granting the molecular constitution of the æther, is it not probable that the Kinetic theory applies more rigidly to it than to the most perfect of the known gases?*

The 133 foot-pounds of energy per second is the solar heat energy in a prism whose base is 1 square foot and altitude 186,300 miles, the distance passed over by a ray in one second; hence the energy in 1 cubic foot will be

$$\frac{133}{186{,}300 \times 5{,}280} = \frac{4}{3 \times 10^7} \text{ foot-pounds}. \quad (1)$$

Where results are given in tenth-units of high order, as in the last expression, it seems an unnecessary refinement to retain more than two or three figures to the left hand of the *tens;* and we will write such expressions as if they were the exact results of the computations.

If V be the velocity of a wave in an elastic medium whose coefficient of elasticity, or in other words, its tension, is e and density δ, both for the same unit, we have the well-known relation

$$V = \sqrt{\frac{de}{d\delta}}.$$

And for gases we have

$$e = \delta^\gamma,$$

where $\gamma = 1.4$; and the differential of the latter substituted in the former gives

$$V = \sqrt{\frac{\gamma e}{\delta}}. \quad . \quad . \quad . \quad . \quad (2)$$

The tension of a gas varies directly as the kinetic energy of its molecules per unit of volume. If v^2 be the mean square of the molecules of a self-agitated gas, we have

$$e \propto \delta v^2, \text{ or } v^2 = x\frac{e}{\delta}, \quad . \quad . \quad (3)$$

where x is a factor to be determined. Equations (2) and (3) give

$$v^2 = \frac{x}{\gamma}V^2. \quad . \quad . \quad . \quad (4)$$

Assuming, with Clausius, that the heat energy of a molecule due to the action of its constituent atoms, whether of rotation or otherwise, is a multiple of its energy of translation, we have for the energy in a unit of volume producing heat,

$$\tfrac{1}{2}y\delta v^2,$$

where y is a factor to be determined. If c be the specific heat of a gas, w its weight per cubic foot at the place where $g=32.2$, J. Joule's mechanical equivalent, τ its absolute temperature; then the essential energy of a cubic foot of the medium will be $cw\tau J$; and observing that $w = g\delta$, we have

$$\tfrac{1}{2}y\delta v^2 = cg\delta\tau J, \quad . \quad . \quad . \quad (5)$$

which, reduced by (4), gives

$$xy = \frac{2cg\gamma\tau J}{V^2}, \quad . \quad . \quad . \quad (6)$$

the second member of which is constant for a given gas. To find its value we have

	Hydrogen.	Air.	Oxygen.
Specific heat* . .	3.4093	0.2375	0.2175
Velocity of sound, feet per second, at τ=493.2° . .	4,163	1,090	1,040

and $g=32.2$, $\gamma=1.4$, $J=772$. These, substituted in the second member of (6), give

xy for hydrogen........	6.599
" air................	6.706
" oxygen...........	6 596
	3)19.901
Mean........	6.63

This value, which is nearly constant for the more perfect gases, we propose to call *the modulus of the gas*, and represent

* See also remarks by G. J. Stoney, *Phil. Mag.*, 1868 [4] xxxvi. pp. 132, 133.

* Stewart on "Heat," p. 229.

it by μ; and for the purposes of this paper we will use

$$\mu=6.6.$$

This relation of the product xy being a constant, has, so far as we are informed, been overlooked by physicists, and is worthy of special notice, since it determines the value of one of the factors when the other has been found. Krönig, Clausius,* and Maxwell give for x the constant number 3, but variable values for y.†

We are confident that the value of x is not strictly constant; or if it is, it exceeds 3, since the effect of the viscosity of a gas would necessitate a larger velocity to produce a given tension than if it were perfectly free from internal friction. For our purpose, it will be unnecessary to find the separate values of x and y; but if we have occasion to use the former in making general illustrations, we will call it 3, as others have done heretofore. If the correct value of x exceeds 3, it will follow that the velocity of the molecules exceeds the values heretofore computed.‡ According to Thomson, Stokes showed that in the case of circularly polarized light the energy was half potential and half kinetic; § in which case $y=2$, and therefore $x=3.3$.

The energy in a cubic foot of the æther at the earth being given by (1) and (5), we have, by the aid of (4),

$$\tfrac{1}{2}y\delta v^2=\tfrac{1}{2}\mu\frac{\delta}{\gamma}\mathrm{V}^2=\frac{4}{3\times10^7}; \quad . \quad . \quad (8)$$

$$\therefore\delta=\frac{4\times1.4\times2}{3\times10^7\times6.6\times(186{,}300\times5280)^2}=$$

$$\frac{2}{35\times10^{24}}\text{ lb.}, \quad . \quad . \quad (9)$$

which is the mass of a cubic foot of the æther at the earth, and which would weigh at the place where $g=32.2$ about

$$w=\frac{2}{10^{24}}\text{ of a pound}, \quad . \quad . \quad (10)$$

compared with which Thomson's value is less than 4,000 times this value. Thomson remarked that the density could hardly be 100,000 times as small—a limit so generous as to include far within it the value given in (9). According to equation (10), a quantity of the æther whose volume equals that of the earth, would weigh about $\frac{1}{20}$ of a pound. If a particle describes the circumference of a circle in the same time that a ray passes over a wave-length λ, the radius of the circle will be, using equation (4),

$$r=\frac{vt}{2\pi}=\sqrt{\frac{x}{\gamma}}.\mathrm{V}.\frac{\lambda}{2\pi\mathrm{V}}=\tfrac{10}{43}\lambda,$$

or the displacement from its normal position will be about $\frac{10}{43}$ of a wave-length, or about $\frac{1}{215000}$ of an inch at the earth.

Eliminating V between (2) and (8) gives

$$e=\frac{8}{3\mu\times10^7}=\frac{4}{10^8} \quad . \quad . \quad . \quad (11)$$

for the tension of the æther per square foot at the earth, and is equivalent to about 1.1 of a pound on a square mile. The tension of the atmosphere at sea level is more than 30,000,000,000 times this value. It somewhat exceeds the tension of the most perfect vacuum yet produced by artificial means, so far as we are informed. Crookes produced a vacuum of .02 millionth of an atmosphere* without reaching the limit of the capacity of the pumps; and Professor Rood produced one of $\frac{1}{390000000}$ of an atmosphere† without passing the limit of action of his apparatus. The latter gives a pressure per square foot of

$$\frac{14.7\times144}{390000000}=\frac{1}{180000}\text{ of a pound.}$$ This, in round numbers, is 140 times the value given in equation (11). Even at this great rarity of the atmosphere, the quantity of matter in a cubic foot of the air would be some 200 million million times the quantity in a cubic foot of the æther—such is the exceeding levity of the æther.

Admitting that the æther is subject to

* *Phil. Mag.*, 1857 [4] xiv. p. 123.

† "Theory of Heat," pp. 314 and 317. Maxwell states that the value for y is probably equal to 1.634 for air and several of the perfect gases. This would make $x=4$ nearly.

‡ Maxwell gives for the mean square of the velocities (or, in other words, the velocity whose square is the mean of the squares of the actual velocities) of the molecules, in feet per second at 493.2° F. above absolute zero, hydrogen 6,232, oxygen 1,572, carbonic oxide 1.672, carbonic acid 1,570. *Phil. Mag.*, 1873, p. 68. Our equation (4) gives for air 1,593.

§ *Phil. Mag.* 1855 [4] ix. p. 37.

* "On the Viscosity of Gases at High Exhaustions," by William Crookes, F. R. S., "Phil. Trans. Roy. Soc.," part ii. (1881), p. 400: "Going up to an exhaustion of 02 millionth of an atmosphere, the highest point to which I have carried the measurements, although by no means the highest exhaustion of which the pump is capable."

† *Journ. of Arts and Science*, 1881, vol. xxii., p. 90.

attraction according to the Newtonian law, and of compression according to the law of Mariotte, we propose to find *the relation between the density of the æther at the surface of an attracting sphere and that at any other point in space*, providing that the sphere be cold and the only attracting body, and the gas considered the only one involved.

Let δ_0, e_0, w_0 be respectively the density, elasticity and weight of a unit of the medium, whether æther, air, or any other gas at the surface of the sphere; δ, e, w, the corresponding quantities at a distance z from the surface of the sphere; r the radius of the sphere, g_0 the acceleration due to gravity at its surface, and g that at distance $r+z$ from the center of the sphere. Then

$$\frac{\delta}{\delta_0}=\frac{e}{e_0}=\frac{w}{g}\div\frac{w_0}{g_0}$$

and

$$g=g_0\frac{r^2}{(r+z)^2};$$

$$\therefore\ e=\frac{e_0}{w_0}\cdot\frac{g_0}{g}w=\frac{e_0}{w_0}\frac{(r+z)^2}{r^2}w. \quad . \quad (12)$$

But

$$de=-wdz=-g\delta dz \quad . \quad . \quad (13)$$

$$\therefore\ \frac{de}{e}=-\frac{g_0\delta_0}{e_0}\cdot\frac{r^2}{(r+z)^2}dz.$$

Integrating between e and e_0, $r+z$ and r, we have

$$e=e_0\varepsilon^{-\frac{g_0\delta_0}{e_0}\cdot\frac{rz}{r+z}}, \quad . \quad . \quad (14)$$

$$\delta=\delta_0\varepsilon^{-\frac{g_0\delta_0}{e_0}\cdot\frac{rz}{r+z}}. \quad . \quad . \quad . \quad (15)$$

Neglecting the attraction of the earth for the æther, and considering the sun as the only attracting body, we have g_0 at the sun 28.6×32.2, and at the earth, $z=210r$, $r=441{,}000$ miles, the sun's radius; $\delta=\frac{2}{35}\times10^{-24}$, equation (9), and $e=\frac{4}{33}\times10^{-6}$; and these, in (14) and (15), give

$$e=e_0\varepsilon^{\frac{28.6\times32.2\times2\times33\times10^6}{4\times35\times10^{24}}\times\frac{210}{211}\times441{,}000\times5280}$$

$$=e_0^{\frac{1}{1{,}000{,}000}}\text{ nearly}, \quad . \quad . \quad (16)$$

and

$$\delta=\delta_0\varepsilon^{\frac{1}{1{,}000{,}000}}\text{ nearly}, \quad . \quad . \quad (16')$$

for the tension and density of the æther at the surface of the sun under the conditions imposed. But the millionth root of ε is practically unity; hence the elasticity and density at the sun is practically the same as at the earth.

Now, starting at the sun with this result, and finding the density at a distance z from it, then making z infinite, we shall get about the 995,000 root of ε, the value of which is also sensibly equal to unity; hence the density at infinity would be sensibly the same as at the surface of the sun, the difference in the densities at the sun and at infinity being less than $\frac{1}{1000000}$ part of that at the sun. In order to make the density vary sensibly with the distance, the attraction of the central body must be something like a million times as great as that of the sun, or have a diameter a million times as large; but there being no such known body, therefore *the density and tension of the æther may be considered uniform throughout space.* Such has been our conception of it, and it is an agreeable surprise to find it so fully confirmed by analysis.

If the density were uniform, the weight of a given volume of it would vary as the force of gravity. At the surface of the sun a cubic foot would weigh [equation (10) multiplied by 28.6, or] 57×10^{-24}; hence, for a height h it would weigh

$$\frac{57}{10^{24}}\int_0^h\frac{r^2}{(r+z)^2}dz=\frac{57}{10^{24}}\cdot\frac{rh}{r+h}, \quad . \quad (17)$$

which for $h=\infty$ becomes $\frac{13}{10^{14}}$ of a pound, which is the pressure upon a square foot of the sun of a column of infinite height under the conditions imposed. This would compress the first foot of the column about $\frac{1}{1000000}$ of its length, and would cause a corresponding increase in the density, the value of which, after this compression, will be found by multiplying the value given in equation (9) by $\frac{999999}{1000000}$, which will leave the result sensibly the same as before. Hence, from this standpoint, we again conclude that the density of the æther may be considered as sensibly uniform throughout space, providing its temperature be essentially uniform.

If we assume that the law of the resistance by which the æther opposes the motion of a body varies as the square of the velocity of the body, we are still unable to assign the coefficient which will give the numerical value; but it is safe to assume that the entire mass of the æther occupying the path of a body moving through it, will not have a velocity imparted to it exceeding that of the body; but, to be on the safe side, we will assume that it imparts a velocity equal to itself. The energy thus imparted will be lost to the body. To simplify the case, consider a planet moving in a circular orbit: r the radius of the planet, d its distance from the sun, D its specific gravity compared with water as unity, v_1 the velocity in its orbit; then the mass of æther occupying the place of the planet during one revolution about the sun will be, using equation (9),

$$\frac{2}{35\times10^{24}}\pi r^2\times2\pi d,$$

which, multiplied by $\frac{1}{2}v_1^2$, will give the energy imparted to it. The kinetic energy of a planet, neglecting its rotation, will be

$$\tfrac{4}{3}\pi r^3\times62\tfrac{1}{2}\mathrm{D}\times\frac{v_1^2}{2g}.$$

Dividing the former, after multiplying it by $\frac{1}{2}v_1^2$, by the latter, gives

$$\frac{1}{7\times10^{24}}\cdot\frac{d}{r\mathrm{D}} \quad . \quad . \quad . \quad . \quad (18)$$

for the fraction of the energy lost during one revolution about the sun. Applying this to the earth, we have

$$d\div r\mathrm{D}=93{,}000{,}000\div3{,}912\times5\tfrac{1}{2}=43{,}000,$$

and (18) becomes

$$\frac{6}{10^{22}} \text{ nearly,} \quad . \quad . \quad (19)$$

for the fraction of the energy lost in one year; and hence *at this rate* would require more than 1,666,000 trillion (1,666,-000,000,000,000,000,000) years to bring it to rest.

Equation (18) is not applicable to the resistance offered to a comet, on account of the elongated orbit of the latter; but some idea of the effect of the resistance of the æther to the movement of a comet may be found by considering what it would be if the orbit were circular, having for its radius the perihelion distance. According to Professor Morrison, the perihelion distance of the great comet (6), 1882,* was 716,200 miles, its aphelion distance will be 5,000,000,000 miles, the diameter of its nucleus shortly before disappearing on the solar disk was 7,600 miles, the velocity at perihelion 295 miles per second, and at aphelion 75 feet per second. But little is known in regard to the density of comets; but, to be on the safe side we will assume it as $\frac{1}{1000}$ that of water. This data will reduce (18) to 13×10^{-18} for the fraction of energy lost during one of its revolutions about the sun; and as it would make a revolution in, say, 20 hours, it would lose in one of our years about 57×10^{-16} of its energy, *at which rate* it would go on for 170 trillions of years. Similarly, at its aphelion its *rate* of loss would be less than $\frac{1}{6}\times10^{-15}$ of its energy in more than 2,000 years—the time of one revolution in its orbit.

The most careful observations and calculations have failed to detect any effect due to the resistance of matter in space; and the above analysis shows that, within historic times, it has in any case scarcely amounted to an infinitesimal, certainly not sufficient to be measured. And when we consider that our assumptions have been very largely on the unfavorable side, and, further, that the energy imparted to the æther may partly, at least, be restored to the body, we assume that its resistance never can be measured. Laplace, when he found that the force of gravitation, if propagated by an elastic medium, must have a velocity exceeding 100 million times that of light, concluded that astronomers might continue to consider its action as instantaneous (*Mécanique Céleste*, B. x., ch. viii., p. 22, 9,035); so may we, with nearly as much confidence, continue to consider the resistance of the æther as *nil.*

Equation (6) gives

$$c\tau=\frac{6.6(186{,}300\times5{,}280)^2}{2\times32.2\times1.4\times772}=92\times10^{12} \quad (20)$$

from which the specific heat of the æther may be found if its temperature were known. M. Fourier, the first to assign a value to *the temperature of space,* assumed it to be somewhat inferior to the temperature at the poles of the earth

* "Monthly Notices of the Royal Astronomical Society," vol. xliv. 2, p. 54.

or about 50° C. to 60° C. below zero.* M. Pouillet, considering the atmosphere as a diathermanous medium, capable of absorbing in different degrees the radiant heat from the sun and the dark heat from the earth, deduced for the heat of space—or, as he and Fourier called it, the stellar heat—approximately—142°C.† (— 287° F.), which is about 174° F. above absolute zero. It is well known that Pouillet's data were imperfect, several important elements being neglected, notably that of the humidity of the air; still, it is not only the first, but, so far as we know, the only attempt to formulate this relation. It served to show what has since been indicated by more direct experiments, that the temperature of space is very low. The delicate experiments of Professor Langley, before referred to, show a great difference in the degree of absorption by our atmosphere of different wave-lengths. The mean of the values for nine different wave-lengths, treated by M. Pouillet's formula, gives 139° F. above absolute zero, and the smallest value of absorption, which was for the infra-red, gives only 71° F. above absolute zero for the heat of space.

The heat of space may be considered as composed of three parts: (1) stellar heat, (2) the heat contained in the dark matter of space, (3) the essential heat of the æther.

1. By the stellar heat we mean the heat received directly from the stars. It is a matter of easy calculation that, if the 50,000,000 of stars supposed to be visible with the most powerful telescopes were all at the distance of the nearest fixed star (*a* Centauri), or 221,000 astronomical units from the earth, and if each radiated the same amount of heat as our sun, the intensity varying as the inverse squares of the distances, the earth would receive from them all less than $\frac{1}{1000}$ as much heat as it now receives from the sun. And when we consider that only a very few stars are within measurable distances, and that the remote ones may be, when compared with these, well-nigh infinitely distant, it is evident that the amount of heat received from the stars is insignificant, and may be discarded at the earth.

2. It is certain that there is a large amount of dark matter in space, since the meteoric dust and meteorites must come from beyond our atmosphere. The zodiacal light is supposed to be an evidence of meteoric matter between the earth and sun. The tails of comets are visible by some action of light upon some kind of matter. Matter in space not exposed to the rays of the sun will be at about the same temperature as the æther; but if in the rays of the sun and destitute of an atmosphere at the distance of the earth from the sun, its temperature would be very low. If present laws can be extended so far, and the earth were without an atmosphere, and the heat received were not conducted away, it has been computed that the mean temperature at the equator would be about −70° C. (−94° F.); and at the poles—221° C.,* or 114° F. above absolute zero. The last result is obtained on the supposition that the poles receive heat directly from the sun a part of the year; it is further shown that if the poles were never exposed to the rays of the sun, the temperature would fall to that of the æther of space. But the data is not uniform, and there is too large an extension of empirical formulae to satisfy one that the above numerical results are reliable; still they point more and more strongly to a temperature not many degrees above absolute zero.

3. By the essential heat of the æther we mean the temperature which would be indicated by a thermometer graduated from absolute zero in a room located in space beyond our atmosphere, whose walls were impervious to the passage of external heat. It is the heat due to the self agitated æther, just as air has a temperature when not exposed to the rays of the sun. If the æther be perfectly diathermanous to the sun's rays, it will receive no heat, on account of the heat of the sun flowing through it, though it may be

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* *Ann. der Chemie*, tome xvii., p. 155.

† *Comptes Rendus*, 1838, vol. 7, p. 61. Pouillet's formula is

$$a^{t'} = 1.235^{\frac{2-b}{2-b'}} - 0.489,$$

in which b' = the absorptive power by the atmosphere of the sun's heat,
b = the absorptive power of terrestrial heat,
t' = the temperature of the stellar heat,
a = 1.0077.

If $b=1$, its maximum, $b'=0.2$, we find $t'=-235°$ C. (−391° F.), or 71° F. above absolute zero.

* "Professional Papers of the Signal Service, U. S. A.," Washington, D. C., 1884, No. xii., p. 54.

heated from other sources. As direct evidence of an extremely low temperature of space, we cite the facts in regard to the meteorite which fell at Dharmsalla, India, July 14, 1860.* "The most remarkable thing about it was, while the mass had been inflamed and melted at the surface, the fragments gathered immediately after the fall and held for an instant were *so cold that the fingers were chilled.* This extraordinary assertion, which is contained in the report with no expression of doubt, indicates that the mass of the meteorite retained in its interior the intense cold of the interplanetary space, while the surface was ignited in passing through the terrestrial atmosphere." Since this body had been exposed to the rays of the sun, its temperature must have exceeded that of the space through which it passed, as well as been warmed by the heat developed at its surface, from which it may be inferred that it had been *intensely* cold. Direct investigations, given above, indicate that this temperature is less than 200° F. above absolute zero; and we cannot assert that it is not less than 100° F. above, or even much less.

But, however low be the temperature of the æther, it cannot be absolutely cold, or, in other words, it must have a temperature above absolute zero. for otherwise it would be destitute of elasticity, and hence incapable of transmitting a wave. This is shown by eliminating V between equations (2) and (6), giving

$$c\tau=\frac{\mu}{2g\delta J}e,\dagger \quad . \quad . \quad . \quad (21)$$

in which if $\tau=0$, e will be zero, all the other factors being finite, and if $e=0$, then V=0 in (2). Indeed, this principle is so well recognized in physics, that a proof in this place seems superfluous. Being unable, in the present state of our knowledge, to do more than assign the probable superior limit of the temperature, we will, for the purposes of this analysis, assume $\tau=20°$ F., absolute, being confident that the actual value is between $\frac{1}{10}$ of and 10 times this value. This value in equation (20) gives

$$c=46\times10^{11}=4{,}600{,}000{,}000{,}000 \quad (22)$$

for the specific heat of the æther, that of water being unity. This number so vastly—we might say infinitely—exceeds that for any known gas, as to justify one, at first thought, in looking with suspicion upon the applicability of the above analysis to this medium. Assumptions in regard to the absolute temperature will scarcely improve the appearance of this number. If it be assumed that the absolute temperature be only one degree, the number in equation (22) would be only twenty times as large; and if the absolute temperature be assumed at 1,000,000° F., the resulting specific heat would still be more than a million times as large as for hydrogen. A few considerations of other properties of the æther may aid one in being reconciled to this paradoxical result. Is the result any more incredible than the fact, everywhere admitted, that every particle of the æther, in transmitting a wave of light, continually makes 590,000,000,000,000 (6×10^{14} nearly) complete cycles of movements every second, for a wave-length of $\frac{1}{50000}$ of an inch? The number of such complete movements in air for the fundamental c is only 264; and hence the ratio of the former to the latter of these numbers is nearly 2×10^{12}. The ratio of the specific heat given in (22) to that of hydrogen is nearly $1\frac{1}{3}\times10^{12}$, which is not so different from that just given for the ratio of cyclical movements in a second of the æther and air. The velocity of sound in air at 493° F. above absolute zero is about 1,090 feet per second; but if the temperature could be reduced to 20° F., absolute, the law being extended so far, the velocity would be only

$$V=109\sqrt{\frac{20}{493}}=217 \text{ feet};$$

but the velocity of light is 982,000,000 feet per second, a number about $4\frac{1}{2}$ million times the former, and near a million of times that of the velocity in air under ordinary conditions. The ratio of the mass of air in a cubic foot at sea-level to that of a cubic foot of the æther as computed, far exceeds any of these ratios. The fact is, the known qualities of the æther in transmitting light and heat so

* *Comptes Rendus*. 1861. tome liii., p. 1018.

† We note that this equation shows that the specific heat for different gases under the same tension, e, and temperature, τ, varies inversely as the density; and for the same temperature and density the specific heats c will be directly as the tension e. The more perfect gases, as hydrogen, oxygen, and air, conform nearly to this law.

far transcend those of any known terrestrial substance, that we might anticipate the fact that, in regard to magnitude, all its properties will be extremely exceptional when compared with such substances. We must accept substantially the number in equation (22), or subject this medium to different laws than those of gases.

We may deduce this result by another process; thus, since the specific heats of different gases are as the squares of the wave-velocities in the respective substances, the other elements being the same, if the specific heat of air be 0.23, we should have for the specific heat of the æther

$$c=0.23\left(\frac{186300\times 5280}{217}\right)^2=46\times 10^{11},$$

as before. The correct value of the specific heat of air, 0.2375, would give over 47×10^{11}, and nearly 48×10^{11}; but these differences are quite immaterial in this connection, the object being to check the former result, and find chiefly qualitative values.

On the other hand, in order that common air might be able to transmit a wave of the known velocity of light, its specific heat being taken constantly at 0.23, its temperature would be, according to equation (20),

$$\tau=\frac{92\times 10^{12}}{0.23}=4\times 10^{14} \text{ degrees F.}$$

$$(=400{,}000{,}000{,}000{,}000^\circ \text{ F.}).$$

If the sun were composed of a substance having such specific heat, it could radiate heat at its present rate for more than a hundred millions of centuries without its temperature being reduced 1° F., exclusive of any supply from external sources, or from a contraction of its volume. We know only such substances in the sun as we are able to experiment with in the laboratory; and if there be an exceptional substance in it, we have no means at present of determining its physical properties. It is, moreover, a question whether the æther constitutes an essential part of bodies. We conceive of it only as the great agent for transmitting light and heat throughout the universe.

On account of the enormous value of the specific heat, it will require an inconceivably large amount of heat (mechanically measured) to increase the temperature of one pound of it perceptibly. Thus, if heat from the sun, by passing through a pound of water at the earth, would raise the temperature 100° F. and maintain it at, say, 600° F., absolute, it would, under similar conditions, raise the temperature of one pound of the æther, if its power of absorption be the same as that of water, $\frac{1}{460000000000}$ of a degree.

The distance of the earth from the sun being 210 times the radius of the latter, the amount of heat passing a square foot of spherical surface at the sun will be about 45,000 times the heat received on a square foot at the earth normally exposed to its rays, so that, under the conditions imposed, the temperature would not be a billionth of a degree F. higher at the sun than at the earth. This, then, is a condition favorable to a sensibly uniform temperature, even if heated by the sun's rays. *We* are now inclined to admit that the æther is not perfectly diathermanous to the sun's rays, but that its temperature, however small, may be due directly to the absorption of the heat of central suns; for we begin to realize the fact that the æther may possess many of the qualities of gases, such as a molecular constitution, and hence also mass, elasticity, specific heat, compressibility, and expansibility, although the magnitude of these properties is anomalous. We have already considered its compressibility at the surface of the sun, due to the weight of an infinite column, and found it to be exceedingly small; now, it may be possible that the expansion due to the excess of temperature of a small fraction of one degree at the surface of the sun over that at remote distances will diminish the density as much, or about as much, as pressure increased it, thereby making the density even more exactly uniform than it otherwise would be. According to what we know of refraction, it is impossible for a ray of light to be refracted in passing through the æther only—at least, not by a measurable amount; for not only are the density and elasticity practically uniform, but their ratio is, if possible, even more constant as shown by equations (16) and (16′). But the freedom of the æther molecules may be constrained, or their velocity impeded, by their entanglement with gross matter, such as the gases and transparent solids in which case refraction may be produced in a ray passing obliquely through strata of varying densities. Neither is it believed that the æther does, or can, reflect light; for if it did, the entire sky would be more nearly luminous. The rays in free space move in right lines.

The masses of the molecules in different gases being inversely as their specific heats, and as the specific heat of hydrogen is 3.4, and the computed mass of one of its molecules $\frac{11}{18}\times10^{-29}$* of a pound, we have for the computed mass of a molecule of the luminiferous æther,

$$m=\frac{11}{18\times10^{29}}\times\frac{3.4}{46\times10^{11}}=\frac{1}{22\times10^{40}}\text{lb.} \quad (23)$$

The mass of a cubic foot of the æther, equation (9), divided by the mass of a molecule, gives the number of molecules in a cubic foot, which will be

$$n=\frac{2}{35\times10^{24}}\times\frac{22\times10^{40}}{1}=\frac{44}{35}\times10^{16}, \quad (24)$$

which call 10^{16}. This number, though large, is greatly exceeded by the estimated number of molecules in a cubic foot of air under standard conditions, which, according to Thomson, does not exceed 17×10^{25}, a number nearly 17,000,000,000 times as large as that in equation (24); and yet, at moderate heights, the number of molecules in a given volume of air will be less than that of the æther.

Assuming that air is compressed according to Boyle's law, and is subjected to the attraction of the earth, equation (15) will give the law of the decrease of the density. Taking the density of air at sea-level at $\frac{1}{400}$ of a pound per cubic foot, $e_0=14.7$ lbs. per square inch, $r=20,687,000$ feet, equation (15) becomes

$$\delta\times\tfrac{1}{400}\times10^{-345\frac{z}{r+z}}. \quad . \quad . \quad (25)$$

If $z=\infty$, $\delta=\frac{1}{400}\times10^{-345}$, which would be the limit of the density, and it is a novel coincidence that this limit is nearly identical with the value found for the density at the height of one radius of the earth according to the ordinary exponential law, wherein gravity is considered uniform.*

If the number of the molecules in a cubic foot follows the same law, then at the height z there will be

$$17\times10^{-345\frac{z}{r+z}+25} \quad . \quad . \quad (26)$$

molecules per cubic foot. Similarly, the value of the length of the mean free path would be†

$$2\times10^{345\frac{z}{r+z}-6}\text{ inches.} \quad . \quad (27)$$

By means of these values, the table which appears on the following page may be formed.

The numbers in the third column multiplied by $\frac{1}{400}$ will give the density (or mass per cubic foot) at the respective altitudes; and the same numbers multiplied by 15 (or, more accurately, 14.7) will give the tension per square inch. According to this law, at an elevation of 300 miles the density of the atmosphere will be somewhat less than the density of the æther as given by equation (9).

To find the height at which the tension of the atmosphere, according to the above law will be the same as that of the

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* Stoney concludes that "it is therefore probable that there are not fewer than something like a unit eighteen (10^{18}) of molecules in a cubic millimeter of a gas at ordinary temperature and pressure" (*Phil. Mag.* 1868 [4] xxxvi. p. 141). According to the Kinetic theory the number of molecules in a given volume under the same pressure and temperature is the same for all gases. The weight of a cubic foot of hydrogen at the temperature of melting ice and under constant pressure being 0.005592 of a pound, and as a cubic foot equals 28,315,000 cubic millimeters, the probable mass of a molecule of hydrogen will be

$$\frac{0.005592}{32.2\times28,315,000\times10^{25}}=\frac{11}{18\times10^{29}}\text{ lb.}$$

Maxwell gives $\frac{46}{10^{25}}$ of a gramme$=\frac{3}{7\times10^{28}}$ lb., which is about 3/5 the value given above (*Phil. Mag.* 1873 [4] xlvi. p. 468).

The difference in these results arises chiefly from the calculated number of molecules in a cubic foot of gas under ordinary conditions. Thomson gives as the approximate probable number 17×10^{25}, which is about 3/5 the value given by Stoney. Thomson's value would make the mass of a molecule of æther about $\frac{1}{13}\times10^{-40}$ of a pound, which is not much different from that found above.

* The ordinary exponential law results from dropping $\frac{z}{r}$ compared with unity in equation (15), giving

$$\delta=\delta_0\varepsilon^{-\frac{z}{26221}}=\delta_0 10^{-\frac{z\text{ ft.}}{60387}}=\tfrac{1}{400}\times10^{-\frac{z\text{ miles}}{11.44}},$$

in the last of which, if $z=3956$, the exponent becomes 345.

† *Phil. Mag.* 1873 [4] xlvi. p. 468.

Height.		Density or tension, that at the earth being unity.	Number of molecules in a cubic foot.	Length of the mean free path.
Fractional parts of earth's radius.	Approximate in miles.			
0	0	1	17×10^{25}	2×10^{-6} inch.
$\frac{1}{79}$	50	$10^{-4.3}$	$17\times10^{20.7}$	$2\times10^{-1.7}$ "
$\frac{1}{39}$	100	$10^{-8.4}$	$17\times10^{16.6}$	$2\times10^{2.4}$ "
$\frac{1}{20}$	200	$10^{-16.4}$	$17\times10^{8.6}$	792,000 miles.
$\frac{1}{14}$	282	10^{-23}	17×10^{2}	31×10^{11} "
$\frac{1}{10}$	395	10^{-31}	17×10^{-6}	31×10^{19} "
$\frac{1}{5}$	800	10^{-57}	17×10^{-32}	31×10^{45} "
1	3956	10^{-172}	17×10^{-147}	31×10^{160} "
2	7912	10^{-230}	17×10^{-205}	31×10^{218} "
∞	∞	10^{-345}	17×10^{-320}	31×10^{333} "

æther, we have, by means of equations (11) and (25), substituting in the latter 2116 for $\frac{1}{400}$,

$$2116\times10^{-345\frac{z}{r+z}}=\frac{4}{10^8},$$

which solved gives

$$z=\frac{r}{31.24}=126.6 \text{ miles},$$

so that at the height of 127 miles the tension would be less than that of the æther, the temperature being uniform.

The mean free path, according to the above law, in which gravity varies as the inverse squares is less, and for great heights much less, than would be found according to the ordinary exponential law. Thus Crookes states that the mean free path of a molecule at the height of 200 miles is about 10,000,000 miles*; but according to the above law it becomes about 792,000 miles.

If a cubic inch of air at sea-level were carried to the height of $\frac{1}{7}$ the radius of the earth, and then allowed to expand freely, so as to become of the computed density of the atmosphere at that point, it would fill a space of $4\times10^{28.12}$ cubic miles, or a sphere whose radius is 2,398,000,000 miles, which is nearly equal to the distance of the planet Neptune from the sun; and there would be less than one molecule to the mile. Such are some of the results of extending a law to extreme cases regardless of physical limitations or of the imperfection of the data on which it is founded. For instance, a uniform temperature is assumed, and, impliedly, an unlimited divisibility of the molecules. The latter is necessary in order to maintain a law of continuity. But modern investigations show that not only air, but all the gases, are composed of molecules of definite magnitudes whose dimensions can be approximately determined; and hence if there be only a few molecules in a cubic foot, and much less if there be but one molecule in a cubic mile, it cannot be claimed that the gas will be governed by the same laws as at the surface of the earth.

To find the Height of the Atmosphere.—The atmosphere will terminate at that height where the vertical repulsive force equals the weight of the particles in the topmost layer. As a first approximation, conceive that the molecules are arranged in horizontal layers and ver-

* "Phil. Trans. Roy. Soc." London, 1881, Part II. p. 389.

tical columns in a prism whose base is one square foot, and whose height extends to the height of the atmosphere; the base of each column of molecules being one of the molecules in the base of the prism. Considering the number of molecules in a cubic foot of air at standard conditions as 17×10^{25}, and the weight of the same as .08 of a pound, we have for the weight of one molecule of air

$$=\frac{8}{17 \times 10^{27}}* \quad . \quad . \quad . \quad (28)$$

The number of molecules along one edge of the bottom layer will be $\sqrt[3]{17 \times 10^{25}}$ nearly; and the number in the bottom layer the square of this number or $170\frac{2}{3} \times 10^{16}$, which, according to the hypothesis, will be the number in the top layer; and this multiplied by the weight of one molecule will give e, the weight in the top layer; and equation (14) will give (the temperature of the column being considered uniform)

$$14.7 \times 144 \times 10^{-345\frac{z}{r+z}} = \frac{170\frac{2}{3} \times 10^{16} \times 8}{17 \times 10^{27}};$$

$$\therefore \quad z = \frac{r}{23.35} = 169 \text{ miles.} \quad . \quad (29)$$

But the temperature is far from being uniform. In regard to a definite mass of a gas, we have the well-known relation

$$\frac{e}{\delta \tau} = \frac{e_0}{\delta_0 \tau_0} = \text{a constant} = \frac{pv}{\tau}, \quad (29')$$

where $p = e =$ the pressure on the base of a prism, and $v =$ the volume.

The value of δ from this equation substituted in (13) gives

$$\frac{de}{e} = -g\frac{\delta_0}{e_0} \cdot \frac{\tau_0}{\tau} dz. \quad . \quad . \quad (30)$$

But with τ an unknown variable this cannot be integrated. If $\tau = \tau_0$ we at once have equation(14). The relation between τ and z is unknown, if indeed there be any algebraic relation between them. It is, however, known that, as a general fact, the temperature decreases with the elevation; although local causes and air-currents often cause this law to be reversed for moderate heights. The best that can be done, in this case, is to find an expression that will represent approximately, the mean values of the temperature. It is usually assumed that the average temperature at the earth is about 59° F. or 60 F., and that for latitudes of, say, 40° N. to 40° S. the perpetual frost-line is from 14,000 to 16,000 feet above sea-level; and observations indicate that the *rate* of decrease of temperature decreases with the height. The last fact is suggestive of an exponential law; hence assuming

$$\tau = \tau_0 \varepsilon^{-\frac{z}{a}}, \quad . \quad . \quad . \quad (31)$$

and making $\tau = 493°$ F., absolute, at the height $z = 15{,}840$ feet and $\tau_0 = 520°$ F., absolute, we find $a = 296{,}000$ (or 56 if z be in miles), and our equation becomes

$$\tau = 520\varepsilon^{-\frac{z \text{ miles}}{56}}. \quad . \quad . \quad (32)$$

This gives

Height, miles.	τ absolute.	Fahr. scale.	Glaisher's observa ions.*
0	520 F.	59° F.	59° F.
1–5	518	57	..
2–5	515	54	..
3–5	513	52	..
4–5	512	51	..
1	510	49	41
2	501	40	32
3	493	32	18
4	484	23	8
5	475	14	— 2
6	467	6	..
7	458	— 3	—11.8
50	212	—249	..
75	136	—325	..
100	87	—374	..
120	65	—396	..
150	36	—425	..
224	9	—452	..

The temperatures given in twenty-five or more reports of balloon ascensions, not only give values the mean of which is fairly represented by the celebrated seven-mile ascent of Mr. Glaisher, but his

* This may be used as a unit for measuring the mass of a cubic foot of the æther. Thus, dividing the value in equation (10) by that in (28) gives 4250; or the mass of æther in a cubic foot is 4250 times the mass of one molecule of air.

* "Travels in the Air," by James Glaisher, F. R. S. p. 50.

figures, given in the fourth column of the table, represent a more uniform law than is common in such reports. Our computed values exceed his observed values at all points except at the surface of the earth, where they agree. In this ascent he reached the point of freezing at the height of two miles, which is lower than the average, as determined by many observations; and, therefore, it appears that equation (31) probably represents the general law better than this single set of observations. The effect, however, of the exponential law is scarcely perceptible within the limits of observation; for the exponent of ε is so small for elevations under seven miles, that it makes the law of decrease of temperature nearly uniform with equal increments of elevation. Thus, omitting fractions, the computed decrease for the first mile is 10°, and the average for seven miles is nearly 9°; but to assume a uniform decrease throughout the column limits its height independently of pressure or other conditions, for it could not extend beyond the point of absolute zero. There is no objection to applying such a law, provided it can be shown to be true—a condition which, at present, is not accepted.

Substituting τ from (31) in (30), and integrating between the limits of z and $z=0$, gives

$$e = e_0 \, \varepsilon^{-\frac{ag\delta_0}{e_0}(\varepsilon^{\frac{z}{a}} -} \; ; \quad . \quad . \quad . \quad (33)$$

which ultimately will equal the weight of the molecules in the top layer. Hence, substituting numbers, we have

$$2116 = \frac{8 \times 170^{\frac{2}{3}} \times 10^{16}}{17 \times 10^{47}} \, \varepsilon^{\frac{296000 \times .08}{2116}(\varepsilon^{\frac{z}{56}} - 1)};$$

which gives

$$e = 86 \text{ miles.} \quad . \quad . \quad . \quad (34)$$

It is evident that the hypothetical column of uniform temperature will be very much shortened by the very low temperature of the higher regions; but there are other conditions which will modify the preceding analysis. The assumptions in regard to layers and columns would not be realized even under statical conditions, and much less for the conditions in nature. Statically, the molecules would arrange themselves more like shot in a pile, each being over the space between the molecules in the layer below, instead of being directly over a molecule. This arrangement would give a less number in the horizontal layers than assumed above. But the hypothesis of constancy in the number of molecules in the layers is open to greater objections. For the distance between them will increase with the elevation on account of the diminution of the pressure of that part of the column above the point considered, and the elastic force will be correspondingly diminished; while, horizontally, in the plane of a layer of the molecules, the elastic force would remain constant. In other words, in the medium arranged as assumed the tension would not be the same in all directions, and hence would be in unstable equilibrium. As a refinement, we notice that in every heavy fluid the downward pressure at every point exceeds the upward by the weight of a molecule.

Considering, now, that the molecules in the hypothetical layers are distributed uniformly throughout the spaces immediately beneath them, the number in the new top layer will be less than in the former case, and the column will rise to a greater height, and hence will exceed 86 miles; and, in turn, the new column would need another correction, and so on. Assuming that the number in the top layer is 10^{10}, and that the vertical component of the elastic forces follows the law of equation (33), we find

$$z = 95 \text{ miles};$$

and if the number in the top layer be 10^4, we find $z=104$ miles, and for *one* molecule, $z=110$ miles. In a similar manner it would be legitimate to assume that the column was capped by a fraction of a molecule, for that would be equivalent to one molecule at the top of a column having a base of several square feet. We are unable to determine where this process would end in nature; and hence this analysis fails to fix definitely the extreme height of the atmosphere, even for statical conditions.

Assuming that the distance between

the contiguous molecules would be inversely as the third root of the densities of the medium, as they would be with sufficient accuracy where the number of molecules in a cubic foot is immense, we have, after substituting e, equation (33), and τ, equation (31), in (29′),

$$\frac{\delta}{\delta_0}=\varepsilon^{\left(\frac{z}{a}-\frac{ag\delta_0}{e_0}\left(\varepsilon^{\frac{z}{a}}-1\right)\right)}=\frac{d_0^{\,3}}{d^{\,3}},$$

where d_0 is the distance between contiguous molecules at sea-level and d the corresponding distance at the height z. Hence

$$d=d_0\left(\varepsilon^{\frac{ag\delta_0}{e_0}\left(\varepsilon^{\frac{z}{a}}-1\right)-\frac{z}{a}}\right)^{\frac{1}{3}} \quad . \quad . \quad (35)$$

If $d_0=\frac{18}{\sqrt[3]{170\times10^8}}$, $\frac{ag\delta_0}{e_0}=11.19$; we have

for $z=$ 86 miles, $d=\frac{1}{95}$ of an inch,
" $z=$ 95 " $d=$ 4.5 inches,
" $z=$104 " $d=$11.4 "

These values of d are greatly in excess of the distances between contiguous molecules in the horizontal layers, according to assumed conditions. Thus, at the height of 104 miles, it was *assumed* that there were 10^2 molecules on the side of a square foot, in which case the distance between contiguous molecules would be about $\frac{1}{8}$ of an inch instead of 11 inches as above. These results ought not to agree exactly, for one analysis assumes that the atmosphere terminates with each assumed number of molecules, while the other assumes that the law is continuous to any height. It is apparent that the laws represented by equations (33) and (35) both become practically discontinuous at a height at or less than 95 miles. For the sake of giving definiteness to the following remarks, we will assume that the mean height for statical conditions is 95 miles. But the conditions in nature are not statical. The changes in temperature in the column will be continually increasing or decreasing its height: the air-currents also operate to change it, first by increasing or decreasing the temperature from the mean at considerable heights, and, secondly, by operating dynamically to push the top of the column upward; the aerial tides may operate to raise the column still higher, and the molecules themselves are supposed to be flying with great rapidity in all directions. An increase of temperature of one-tenth the mean value, which, at the earth's surface would be about 49° F., would elongate the column about ten miles, and a corresponding decrease would shorten it about the same amount, making it 105 miles in the former case and 85 miles in the latter. The effect of air-currents and aerial tides cannot be so definitely calculated; but it is safe to assume that they may produce a much greater increase of height above the mean than they will depression below the mean; just as in a highly agitated sea, the depressions below the mean surface-level may be small compared with the height above the same level to which the spray from the top of a wave may be thrown. It seems possible, therefore, that when the temperature, air-currents, and aerial tides conspire to depress the column, the extreme height of the atmosphere may be reduced to less than 85 miles; and when they conspire to elevate it, it may possibly rise to a height exceeding 120 miles.

If it be certain, as is assumed, that meteors are rendered incandescent by atmospheric friction, and the extreme height at which they are visible could be determined by direct observation, it would fix a height less than the extreme height of the atmosphere, independent of other physical considerations; but the movement of these bodies is so extremely rapid that it is impossible to determine their height with astronomical precision. Still, computations by Professor Herschel give a height of about 118 miles,* and Professor Newcomb estimates it to be about 100 miles.† It is possible that a meteor would sometimes become inflamed by penetrating the atmosphere only a few miles, for although the atmosphere in

* Professor A. S. Herschel gives the height of 20 meteors varying from 40 to 118 miles.—*Nature*, vol. iv. p. 504.

† Newcomb says: "The lightning-like rapidity with which the meteors darted through their course rendered it impossible to observe them with astronomical precision; but the general result was that they were first seen at an average height of 75 miles and disappeared at a height of 55 miles. There was no positive evidence that any meteor commenced at a height greater than 100 miles. These phenomena seem to indicate that our atmosphere really extends to a height of 100 and 110 miles."—"Popular Astronomy," 1878, p. 389.

the upper regions is extremely rare, yet the actual number of molecules in a cubic foot is large. Thus, according to our analysis, for statical conditions, the topmost cubic foot of the 104-mile column would contain about 1,000,000 molecules; and at the height of 95 miles it would contain about 1,000,000,000,000,000 molecules; so that if the relative velocities of the meteor and air be 20 miles per second, the meteor would encounter an *enormous* number in the twentieth or even the hundredth part of a second, after first entering the atmosphere.

The height of the auroral arch—supposed to be within our atmosphere—has been computed to be from 33 to 1,000 miles (see article *Aurora*, "Encyclopœdia Britannica"). But it has been shown by experiment, that a vacuum may be produced through which an electrical discharge cannot be passed, and yet the atmosphere at the height of 150 miles under the most favorable condition, that of uniform temperature, is vastly more rare than the most perfect vacuum ever produced by the most perfect Sprengel pump; and at the height of 200 miles under the same conditions the vacuum would be some 10,000,000 times as great as the most perfect vacuum yet made; while, according to the probable law of the decrease of temperature with the elevation, and in accordance with the probable mass of a molecule of air, the extreme height falls far short of 150 miles. It is evident, therefore, that the assumed determination of the height of the atmosphere by means of the auroral arch is, to say the least, unreliable.*

We have pursued this digression in regard to the atmosphere partly for its own sake and partly to show, by way of contrast and accumulative evidence, that the æther is a substance entirely distinct from that of the atmosphere,—that the former cannot be considered as the latter greatly rarefied, as some have supposed. Admitting the validity of the preceding discussion, some of the distinctive properties are:

1. The different modes of the movements of the molecules in the two substances in the propagation of a wave; in one the motion being a to-and-fro movement and in the other a transverse movement. These are distinctions recognized by the best writers upon the subject, and are especially noticed by Maxwell in an article on *Ether* in the "Encyclopœdia Britannica."

2. It is impossible for a wave to be transmitted in air with the known velocity of light, unless its temperature be increased millions of millions of degrees Fahrenheit above the standard temperature; but such a wave is transmitted in the æther although its temperature is far less than has ever been produced by artificial means.

3. The ratio of the elasticity to the density in the æther is exceedingly large compared with the same ratio in air. The temperature of air being taken at 60° F., and the æther at 20° F., absolute, the ratio is, with sufficient accuracy,

$$\left(\frac{980,000,000}{1,090}\right)^2=8\times10^{11}.$$

4. The specific heat of the æther is, at least, many million times that of air, or of any other known gas.

5. The atmosphere is of variable density, elasticity, and temperature, while the æther is well-nigh isometric throughout space in regard to each of these elements.

6. A molecule of æther is well-nigh infinitesimal compared with one of air.

7. Air is attracted to a planet with such a relative force, that its extreme height is only a few miles.

8. The ratio of the density to the elasticity of the æther is constant; but in the atmosphere, on account of the decrease of temperature with the elevation, the density decreases less rapidly than the elasticity, as may be seen by comparing the first part of equation (35) with equation (33), we have

$$\frac{\delta}{\delta_0}=\varepsilon^{\frac{z}{a}}\cdot\frac{e}{e_0}.$$

On this account a wave would be propagated with less velocity in the higher regions of the atmosphere than in the lower, while a wave in the æther has a sensibly uniform velocity throughout space.

The question may arise, May not the resistance of the æther drag away the re-

* Some writers incline to the view that the aurora is due to a cosmic rather than a terrestrial origin.—*Science*, 1885, p. 395.

mote molecules of the atmosphere, and so scatter them in space along the path of the earth's orbit? Assuming that the atmosphere is moving with the earth through space at the rate of 20 miles per second (which exceeds the actual velocity), and that the resistance of the æther is measured in the same manner as for fluids, we have for the resistance

$$R = kwa\frac{v^2}{2g},$$

where v is the velocity of a molecule of air a its meridian section, w the weight of a unit of volume of the æther, and k a coefficient depending upon the form of the body. Making $k=1$, which is greater than its actual value, and $a=\frac{1}{10^{17}}$ feet, which, again, is in excess of the true area, w the value in equation (10), we find that

$$R = \frac{2}{10^{24}} \times \frac{1}{10^{17}} \times (20 \times 5{,}280)^2.$$

$$\frac{1}{64.4} = \frac{1}{10^{33}} \text{ of a pound nearly.}$$

The attractive force of the earth for a molecule of air is given in equation (28), and hence the attraction of the earth for a molecule of air will exceed 500,000 times the resistance of the æther; hence the molecules of air accompany the earth in its orbit as certainly as does the moon, and are more rigidly bound to it than is its satellite.

The kinetic energy of a molecule of air at standard conditions is about

$$\frac{1}{2} \cdot \frac{8}{32.2 \times 17 \times 10^{27}} 1{,}600^2 = \frac{2}{10^{23}}$$

foot-pound;

and of the æther, according to our results, about

$$\frac{1}{2} \cdot \frac{1}{22 \times 10^{40}} (273{,}000 \times 5{,}280)^2 = \frac{1}{2 \times 10^{23}}$$

foot-pound;

which results are nearly the same; but in a pound of the æther there is some 100,000,000,000 times the kinetic energy of a pound of air.

Considering the terrestrial atmosphere as equivalent to one of uniform density and $5\frac{1}{2}$ miles high, each of whose molecules has a mean square velocity of 1,600 feet per second, and the æther of uniform density, each of whose molecules has the mean square velocity of 286,000 miles per second, a rough approximation shows that the kinetic energy of the æther in a sphere whose radius is 92,000,000 miles (nearly the distance of the earth from the sun) will be only about 100,000 times that in our atmosphere.

The mean free path of a molecule of gas, as given by Loschmidt, is

$$l = \frac{\text{combined volume of the molecules}}{\text{volume of the gas} \times \frac{1}{8} \text{ the diameter of a molecule}},$$

and by Maxwell,

$$l = \frac{\mu}{\rho} \cdot \frac{1}{v} = 3\frac{\mu}{\rho} \cdot \frac{z}{\gamma V};$$

(the last member of which we have added), in which ρ is the density of the gas, μ the coefficient of internal friction, and v the velocity whose square is the mean of the squares of the actual velocities of the molecules. In regard to the æther, these equations contain at least three unknown quantities, l, μ, and the diameter of a molecule, and hence they cannot be completely solved. Comparative results, however, may be found by assuming that the density of the molecules of æther equals those of hydrogen, or is any multiple thereof; for then the diameter of a molecule of the æther might be found (that of hydrogen being 5.6×10^{-10} of a meter); and the combined volume in a cubic foot will equal the number of molecules in a cubic foot multiplied by the volume of one molecule, and hence will be found the length of the mean free path and the coefficient of internal friction.

We conclude, then, that a medium whose density is such that a volume of it equal to about twenty volumes of the earth would weigh one pound, and whose tension is such that the pressure on a square mile would be about one pound, and whose specific heat is such that it would require as much heat to raise the temperature of one pound of it 1° F. as it would to raise about 2,300,000,000 tons of water the same amount, will satisfy the requirements of nature in being able to transmit a wave of light or heat 186,300 miles per second, and transmit 133 foot-pounds of heat-energy from the sun to the earth each second per square foot of surface normally exposed, and also be everywhere practically non-resisting and sensibly uniform in temperature, density and elasticity. This medium we call the Luminiferous Æther.

THE SURVEY OF INDIA.

By General J. T. WALKER, C. B., LL. D., F. R. S.

Abstract of Address before Geographical Section of British Association.

Scientific geography embraces a wide range of subjects, wider than can be claimed for any other department of science. Thus the president of this Section has a vast field from which to gather subjects for his opening address. I shall, however, restrict my address to the subject with which I am most familiar, and give you some account of the survey of India, and more particularly of the labors of the trigonometrical or geodetic branch of that survey, in which the best years of my life have been passed.

I must begin by pointing out that the survey operations of India have been very varied in nature, and constitute a blending together of many diverse ingredients. Their origin was purely European, nothing in the shape of a general survey having been executed under the previous Asiatic governments; lands had been measured in certain localities, but merely with a view to acquiring some idea of the relative areas of properties, in assessing on individuals the share of the revenue levied on a community; but other factors than area—such as richness or poverty of soil, and proximity or absence of water—influenced the assessment, and often in a greater degree, so that very exact measurements of area were not wanted for revenue purposes, and no other reason then suggested itself why lands should be accurately measured. The value of accurate maps of individual properties, with every boundary clearly and exactly laid down, was not thought of in India in those days, and indeed has only of late years begun to be recognized by even the British Government. The idea of a general geographical survey never suggested itself to the Asiatic mind. Thus, when Englishmen came to settle in India, one of their first acts was to make surveys of the tracts of country over which their influence was extending, and as that influence increased, so the survey became developed from a rude and rapid primary delineation of the broad facts of general geography, to an elaborately executed and artistic delineation of the topography of the country, and in some provinces to the mapping of every field and individual property. Thus there have been three orders or classes of survey, and these may be respectively designated geographical, topographical, and cadastral; all three have frequently been carried on *pari passu*, but in different regions, demanding more or less elaborate survey, according as they happened to be more or less under British influence. There is also the Great Trigonometrical or Geodetic Survey, by which the graphical surveys are controlled, collated, and coordinated, as I will presently explain.

Survey operations in India began along the coast lines before the commencement of the seventeenth century, the sailors preceding the land surveyors by upwards of a century. The Directors of the East India Company, recognizing the importance of correct geographical information for their mercantile enterprises, appointed Richard Hakluyt, Archdeacon of Westminster, their historiographer and custodian of the journals of East Indian voyages, in the year 1601, within a few weeks of the establishment of the company by royal charter. Hakluyt gave lectures to the students at Oxford, and is said by Fuller to have been the first to exhibit the old and imperfect maps and the new and revised maps for comparison in the common schools, "to the singular pleasure and great contentment of his auditory." The first general map of India was published in 1752 by the celebrated French Geographer D'Anville, and was a meritorious compilation from the existing charts of coast lines and itineraries of travelers.

But the Father of Indian Geography, as he has been called, was Major Rennel, who landed in India as a midshipman of the Royal Navy in 1760, distinguished himself in the blockade of Pondicherry, was employed for a time in making surveys of the coast between the Paumben Passage and Calcutta, was appointed Surveyor of the East India Company's dominions in Bengal in 1764, was one of the first officers to receive a commission in the Bengal Engineers on its formation, and in 1767 was raised to the position of Surveyor-General. Bengal was not in those days the tranquil country we have known it for so many years, but was infested by numerous bands of brigands who professed to be religious devotees, and with whom Rennel came into collision in the course of one of his surveying expeditions, and was desperately wounded; he had to be taken 300 miles in an open boat for medical assistance, the natives meanwhile applying onions to his wounds as a cataplasm. His labors in the survey of Bengal lasted over a period of nineteen years, and embraced an area of about 300,000 square miles, extending from the eastern boundaries of Lower Bengal to Agra, and from the Himalayas to the borders of Bandelkand and Chota Nagpur. Ill health then compelled him to retire from the service on a small pension and return to England; but not caring, as he said, to eat the bread of idleness, he immediately set himself to the utilization of the large mass of geographical materials laid up and perishing in what was then called the India House; he published numerous charts and maps, and eventually brought out his great work on Indian Geography, the "Memoir of a Map of Hindostan," which went through several editions; this was followed by his Geographical System of Herodotus, and various other works of interest and importance. His labors in England extended over a period of thirty-five years, and their great merits have been universally acknowledged.

Rennell's system of field work in Bengal was a survey of routes checked and combined by astronomical determinations of the latitude and the longitude, and a similar system was adopted in all other parts of India until the commencement of the present century. But in course of time the astronomical basis was found to be inadequate to the requirements of a general survey of all India, as the errors in the astronomical observations were liable materially to exceed those of the survey, if executed with fairly good instruments and moderate care. Now this was no new discovery, for already early in the eighteenth century the French Jesuits who were making a survey of China, with the hope of securing the protection of the Emperor, which they considered necessary to favor the progress of Christianity, had deliberately abandoned the astronomical method and employed triangulation instead. Writing in the name of the missionaries who were associated with him in the survey, Père Regis enters fully into the relative advantages of the two methods, and gives the trigonometrical the preference, as best suited to enable the work to be executed in a manner worthy the trust reposed in them by a wise prince, who judged it as of the greatest importance to his State. "Thus," he says, "we flatter ourselves we have followed the surest course, and even the only one practicable in prosecuting the greatest geographical work that was ever performed according to the rules of art."

What was true in those days is true still; points whose relative positions have been fixed by any triangulation of moderate accuracy present a more satisfactory and reliable basis for topographical survey than points fixed astronomically. Though the lunar theory has been greatly developed since those days by the labors of eminent mathematicians, and the accuracy of the lunar tables and star catalogues is much increased, absolute longitudes are still not susceptible of ready determination with great exactitude; moreover, all astronomical observations, whether of latitude or longitude, are liable to other than intrinsic errors, which arise from deflection of the plumb-line under the influence of local attractions, and which of themselves materially exceed the errors that would be generated in any fairly executed triangulation of a not excessive length, say not exceeding 500 miles.

Thus at the close of the last century Major Lambton, of the 33d Regiment, drew up a project for a general triangulation of Southern India. It was strongly supported by his commanding officer, Colonel Wellesley, afterwards the Duke of Wellington, and was readily sanctioned by the Madras Government; for a large accession of territory in the center of the peninsula had been recently acquired, as the result of the Mysore campaign, by which free communication had been opened between the east and west coasts of Coromandel and Malabar, and the proposed triangulation would not merely furnish a basis for new surveys, but connect together various isolated surveys which had already been completed or were then in progress. The Great Trigonometrical Survey of India owes its origin as such, and its simultaneous inception as a geodetic survey, to Major Lambton, who pointed out that the trigonometrical stations must needs have their latitudes and longitudes determined for future reference just as the discarded astronomical stations, not, however, by direct observation, but by processes of calculation requiring a knowledge of the earth's figure and dimensions. But at that time the elements of the earth's figure were not known with much exactitude, for all the best geodetic arcs had been measured in high latitudes, the single short and somewhat questionable arc of Peru being the only one situated in the vicinity of the equator. Thus additional arcs in low latitudes, as those of India, were greatly needed and might be furnished by Lambton. He took care to set this forth very distinctly in the programme which he drew up for the consideration of the Madras Government, remarking that there was thus something still left as a desideratum for the science of geodesty, which his operations might supply, and that he would rejoice indeed should it come within his province "to make observations tending to elucidate so sublime a subject."

Lambton commenced operations by measuring a base line and a small meridional arc near Madras, and then, casting a set of triangles over the southern peninsula, he converted the triangles on the central meridian into a portion of what is now known as the Great Arc of India, measuring its angles with extreme care, and checking the triangulation by base lines measured at distances of two to three degrees apart in latitude. His principal instruments were a steel measuring chain, a great theodolite, and a zenith sector, each of which had a history of its own before coming into his hands. The chain and zenith sector were sent from England with Lord Macartney's Embassy to the Emperor of China, as gifts for presentation to that potentate, who, unfortunately, did not appreciate their value and declined to accept them; they were then made over to Doctor Dinwiddie, the astronomer to the embassy, who took them to India for sale. The theodolite was constructed in England for Lambton, on the model of one in use on the Ordnance Survey; on its passage to India it was captured by the French frigate, the *Piemontaise*, and landed at Mauritius, but eventually it was forwarded to its destination by the chivalrous French Governor, De Caen, with a complimentary letter to the Governor of Madras.

Lambton was assisted for a short time by Captain Kater, whose name is now best known in connection with pendulum experiments and the employment of the seconds pendulum as a standard of length, but for many years afterwards he had no officer to assist him. At first he met with much opposition from advocates of the discarded astronomical method, who insisted on its being sufficiently accurate and more economical than the trigonometrical. But he was warmly supported by Maskelyne, the Astronomer-Royal in England, and soon had an opportunity of demonstrating the astronomical method to be fallacious, for its determination of the breadth of the peninsula in the latitude of Madras was proved by the triangulation to be forty miles in error. Still, for several years he never received a word of sympathy, encouragement, or advice either from the Government or from the Royal Society. A foreign nation was the first to recognize the importance of his services to science, the French Institute electing him a corresponding member in 1817. After this, honors and applause quickly followed from his own countrymen. In 1818 the Governor-General of India, then the Marquis of Hastings, decided that the survey should be withdrawn from the supervision of a local Government and placed under the Supreme Government, with a view to its extension over all India, remarking at the same time that he was "not aware that with minds of a certain order he might lay himself open to the idle imputation of vainly seeking to partake of the gale of public favor and applause which the labors of Colonel Lambton had recently attracted;" but as the survey had reached the northern limits of the Madras Presidency, its transfer to the Supreme Government, if it was to be further extended, had become a necessity. He directed the transfer to be made, and the survey to be called in future the Great Trigonometrical Survey of India. Noticing that the intense mental and bodily labor of conducting it was being performed by Lambton alone, that his rank and advancing age demanded some relief from such severe fatigue, and further that it was not right that an undertaking of such importance should hang on the life of a single individual, the Governor-General appointed two officers to assist him, Captain Everest, as chief assistant in the geodetic operations, and Dr. Voysey, as surgeon and geologist. Five years afterwards Lambton died, at the age of seventy. The happy possessor of an unusually robust and energetic constitution and a genial temperament, he seems to have scarcely known a day's illness, though he never spared himself nor shrank from subjecting himself to privations and exposure which even Everest thought reckless and unjustifiable. These he accepted as a matter of course, saying little about them, and devoting his life calmly and unostentatiously to the interests of science and the service of his country.

Everest's career in the survey commenced disastrously. He was deputed by Lambton to carry a triangulation from Hyderabad, in the Nizam's territory, eastward to the coast, crossing the forest-clad and fever-haunted basin of the Godavery river, a region which he described as "a dreadful wilderness, than which no part of the earth was more dreary, desolate, and fatal." Indignant at being taken there, his escort, a detachment of the Nizam's troops, mutinied, and soon afterwards he and his assistants and almost all the men of his native establishment were stricken down by a malignant fever; many died on the spot, and the survivors had to be carried into Hyderabad, whence litters and vehicles of all descriptions, and the whole of the public elephants, were dispatched to their succor. To recover his health Everest was compelled to leave India for a while and proceed to the Cape of Good Hope, where he remained for three years. He availed himself of the opportunity to inspect Lacaille's meridional arc, which, when compared with the arcs north of the equator, indicated that the opposite hemispheres of the globe were seemingly of different ellipticities. He succeeded in tracing this anomaly to an error in the astronomical amplitude of the arc, which had been caused by deflection of the plumb-line at the ends of the arc, under the influence of the attraction of neighboring mountains. Thus he became aware of the necessity of placing the astronomical stations of the Indian arcs at points where the plumb-line would not be liable to material deflection by the attraction of neighboring mountain ranges. Shortly after his return to India Lambton died, and Everest succeeded him, and immediately concentrated his energies on the extension of the Great Arc northwards. He soon came to the conclusion that his instrumental equipment, though good for the time when it was procured, and amply sufficient for ordinary geographical purposes, was inadequate for the requirements of geodesy, and generally inferior to the equipments of the geodetic surveys then in progress in Europe. He therefore proceeded to Europe to study the procedure of the English and French surveys, and also to obtain a supply of new instruments of the latest and most improved forms. The Court of Directors of the Honorable East India Company accorded a most liberal assent to all his proposals, and gave him *carte blanche* to provide himself with whatever he considered desirable to satisfy all the requirements of science.

Everest returned to India with his new instrumental equipment in 1830, a year that marks the transition of the character of the operations from an order of accuracy which was sufficient as a basis for the graphical delineation of a comparatively small portion of the earth's surface, to the higher precision and refinement which modern geodesists have deemed essentially necessary for the determination of the figure and dimensions of the earth as a whole. He immediately introduced an important modification of the general design of the principal triangulation, which up to that time had been thrown as a network over the country on either side of the Great Arc, as in the English survey and many others; but he abandoned this method, and, adopting that of the French survey instead, he devised a system of meridional chains to be carried at intervals of about 1° apart, and tied together by longitudinal chains at intervals of about 5°, the whole forming, from its resemblance to the homely culinary utensil with which we are all familiar, what has been called the gridiron system in contradistinction to the network. The entire triangulation was to rest on base lines to be measured with the new Colby apparatus of compensation bars and microscopes which had been constructed to supersede the measuring chain the Emperor of China had rejected; the base lines were to be placed at the intersections of the longitudinal chains of triangles with the central meridional or axial chain, and also at the further angles of the gridirons on each side. Latitudes were to be measured at certain of the stations of the central chain, with new astronomical circles in place of the old zenith sector, to give the required meridional arcs of amplitude. Two radical improvements on all previous procedure were introduced in the measurement of the principal angles, one affecting the observations, the other the objects observed. The great theodolites were manipulated in such a manner as not merely to reduce the effects of accidental errors by numerous repititions in the usual way, but absolutely to eliminate all periodic errors of graduation by systematic changes of the position of the azimuthal circle relatively to the telescope, in the course of the complete series of measures of every angle. The objects formerly observed had been cairns of stones or other opaque signals; for these Everest substituted luminous signals, lamps by night, and, by day, heliotropes which were manipulated to reflect the sun's rays through diaphragms of small aperture, in pencils appearing like bright stars, and capable of penetrating a dense atmosphere through which distant opaque objects could not be seen.

Everest's programme of procedure furnished the guiding principles on which the operations were carried out during the period of half a century which intervened between their commencement under his superintendence and the completion of the principal triangulation under myself. The external chains have necessarily been taken along the winding course of the frontier and coast lines, instead of the direct and more symmetrical lines of the meridians and the parallels of latitude. The number of the internal meridional chains has latterly been diminished by widening the spaces between them, and in two instances a principal chain has been dispensed with, because, before it could be taken in hand, a good secondary triangulation had been carried over the area for which it was intended to provide. But these are departures from the letter rather than the spirit of Everest's programme which has been faithfully followed throughout, first by his immediate successor, Sir Andrew Waugh, and afterwards by myself, thus affording an instance of the impress of a single mind on the work of half a century, which is probably unique in the annals of India, for here, as is well known, changes of personal administration are frequent, and are not uncommonly followed by changes of procedure.

The physical features of a country necessarily exercise a considerable influence on the operations of any survey that may be carried over it, and more particularly on those of a geodetic survey, of which no portion is allowed to fall below a certain standard of precision. Every variety of feature, of scenery, and of climate that is to be met with anywhere on the earth's surface between the equator and the arctic regions has its analogue between the highlands of Central Asia and the ocean, which define the limits of the area covered by the Indian survey. Thus in some parts the operations were accomplished with ease, celerity, and enjoyment, while in others they were very difficult and slow of progress, always entailing great exposure, and at times very deadly. In an open country, dotted with hills and commanding eminences, they advanced as on velvet; in close country, forest-clad, or covered with other obstacles to distant vision, they were greatly retarded, for there it became necessary either to raise the stations to a sufficient height to overlook all surrounding obstacles, or to render them mutually visible by clearing the lines between them, and both these processes are more or less tedious and costly. There are many tracts of forest and jungle which greatly impeded the operations, not merely because of the physical difficulties they presented, but because they teemed with malaria, and were very deadly during the greater portion of the year, and more particularly immediately after the rainy season, when the atmosphere is usually clearest and most favorable for distant observations. At first tracts of forest, covering extensive plains, were considered impracticable; thus Lambton carried his network over the open country, and stopped it whenever it reached a great plain covered with forest and devoid of hills; but Everest's system would not permit of any break of continuity, nor the abandonment of any chain which was required to complete a gridiron; it has been carried out in all its integrity, often with much sacrifice of life, but never with any shrinking on the part of the survey officers from carrying out what it had become a point of honor with them to accomplish, and the accomplishment of which the Government had come to regard as a matter of course. We have already seen how the progress of Everest's first chain of triangles was suddenly arrested because he and all his people were struck down by malaria in the pestilential regions of the Godavery basin. That chain remained untouched for fifty years; it was then resumed and completed, but with the loss of the executive officer, Mr. George Shelverton, who succumbed when he had not yet reached, but was within sight of, the east coast line, the goal toward which his labors were directed. Many regions, as the basin of the Mahanaddi, the valley of Assam, the hill ranges of Tipperah, Chittagong, Arracan, and Burma, and those to the east of Moulmein and Tennasserim, which form the boundary between the British and the Siamese territories, are covered with dense forest, up to the summits of the peaks which had to be adopted as the sites of the survey stations. As a rule the peaks were far from the nearest habitation, and they could not be reached until pathways to them had been cut through forests tangled with a dense undergrowth of tropical jungle; not unfrequently large areas had to be cleared on the summits to open out the view of the surrounding country. Here the physical difficulties to be overcome were very considerable, and they were increased by the necessity that arose, in almost every instance, of importing laborers from a great distance to perform the necessary clearances. But the broad belt of forest tract known as the Terai, which is situated in the plains at the feet of the Nepalese Himalayas, was the most formidable region of all, because the climate was very deadly for a great portion of the year, and more particularly during the season when the atmosphere was most favorable for the observations, though the physical difficulties were not so great as in the hill tracts just mentioned, and labor was more easily procurable. Lying on the British frontier, at the northern extremities of no less than ten of the meridional chains of triangles, it had necessarily to be operated in to some extent, and Everest wished to carry the several chains across it, on to the outer Himalayan range, and then to connect them together by a longitudinal chain running along the range from east to west, completing the gridiron in this quarter. But the range was a portion of the Nepalese territories, and all Europeans—excepting those attached to the British embassy at Khatmandu—were debarred from entering any part of Nepal, by treaty with the British Government. Everest hoped that the rulers of Nepal might make an exception in his favor for the prosecution of a scientific survey; and when he found they would not, he urged the Government to compel them to give his surveyors access, at least, to their outlying hills; but he urged in vain, for the Government would not run the risk of embarking in a war with Nepal for purely scientific purposes. Thus the connecting chain of triangles—now known as the N. E. Longitudinal Series—had to be carried through the whole length of the Terai, a distance of about 500 miles, which involved the construction of over 100 towers, raised to a height of about 30 feet to overlook the earth's curvature, and the clearance of about 2,000 miles of line through forest and jungle to render the towers mutually visible. It required no small courage on Everest's part to plunge his surveyors into this region; he endeavored to minimize the risks as much as possible by taking up the longitudinal chain in sections, bit by bit, on the completion of the successive meridional chains, and thus apportioning it between several survey parties, each operating in the Terai for a short time, instead of assigning it to a single party to execute continuously from end to end, as all the other chains of triangles. But notwithstanding these precautions, the peril was great, and the mortality among both officers and men was very considerable; greater than in many a famous battle, says Mr. Clements Markham, in an eloquent passage in his Memoir of the Indian Surveys, in which he claims for the surveyors who were employed on these operations—with no hope of reward other than the favorable notice of their immediate chief and colleagues—merit for more perilous and honorable achievement than much of the military service which is plentifully rewarded by the praises of men and prizes of all kinds.

Everest retired in 1843, and was succeeded by Waugh, who applied himself energetically to the completion of the several chains of triangles exterior to the Great Arc, for which he obtained a substantial addition to the existing equipment of great theodolites. It was under him that the formidable longitudinal series, through the Terai, which had been begun by Everest, was chiefly carried out. He personally initiated the determination of the positions and heights of the principal snow peaks of the Himalayan ranges; and he did much for the advancement of the general topography of India, which had somewhat languished under his predecessor, who had devoted himself chiefly to the geodetic operations. He retired in 1861, and I succeeded to the charge of the Great Trigonometrical Survey. The last chain of the principal triangulation was completed in 1882, shortly before my own retirement.

On the general character of the operations, it may be asserted without hesitation that a degree of accuracy and precision has been attained which has been reached by few and surpassed by none of the great national surveys carried out in other parts of the world, and which leaves nothing to be desired even for the requirements of geodesy; a very considerable majority of the principal angles have been measured with the great 24-inch and 36-inch theodolite, and their theoretical probable error averages about a quarter of a second; of the linear measurements the probable error, so far as calculable may be taken as not exceeding the two-millionth part of any measured length. And as regards the extent of the triangulation, if we ignore the primary network in Southern India, and all secondary triangulation, however valuable for geographical purposes, we still have a number of principal chains—meridional, longitudinal, and oblique—of which the aggregate length is 17,300 miles, which contain 9,230 first-class angles all observed, and rest on 11 base lines measured with the Colby apparatus of compensation bars and microscopes. This prodigious amount of field work furnishes an enormous mass of interdependent angular and linear measures, and each of these is fallible in some degree, for, great as was the accuracy and care with which they had severally been executed, perfect accuracy of measurement is as yet beyond human achievement; thus every circuit of triangles, every chain closing on a base line, and even every single triangle, presented discrepancies the magnitude of which was greater or less according as derived from a combination of many, or only of a few, of the fallible facts of observation. Thus, when the field operations were approaching their termination, the question arose as to how these facts were to be harmonized and rendered consistent throughout, which was a very serious matter considering their great number. The strict application of mathematical theory to a problem of this nature requires the adjustment to be effected by the application of a correction to every fact of observation, not arbitrarily, but in such a manner as to give it its proper weight, neither more nor less, in the final investigation, and in this the whole of the facts must be treated simultaneously. That would have involved the simultaneous solution of upwards of 4,000 equations between 9,230 unknown quantities, by what is called the method of minimum squares, and I need scarcely say that it is practically impossible to solve such a number of equations between so many unknown quantities by any method at all. Thus a compromise had to be made between the theoretically desirable and the practically possible. It would be out of place here to attempt to describe the method of treatment which was eventually adopted, after much thought and deliberation; I will merely say that the bulk of the triangulation was divided into five sections, each of which was treated in succession with as close approximation to the mathematically rigorous method as was practically possible; but even then the mass of simultaneous interdependent calculation to be performed in each instance was enormous, I believe greatly exceeding anything of the kind as yet attempted in any other survey. But the happy result of all this labor was that the final corrections of the angles were for the most part very minute, less than the theoretical probable errors of the angles, and thus fairly applicable without taking any liberties with the facts of observation. If the attribute of beauty may ever be bestowed on such things as small numerical quantities, it may surely be accorded to these notable results of very laborious calculations, which, while in themselves so small, were so admirably effective in introducing harmony and precision throughout the entire triangulation.

If, now, we turn once more to what Lambton calls "the sublime science of geodesy," which was held in such high regard by both him and Everest, we shall find that the great meridional arc between Cape Comorin and the Himalayas, on which they labored with so much energy and devotion, is not the only contribution to that science to which the Indian triangulation is subservient, but every chain of triangles—meridional, longitudinal, or oblique—may be made to throw light either on geodesy, the science of the figure of the earth, or on geognosy, the science of the earth's interior structure, when combined with corresponding astronomical arcs of amplitude. Thus, each of the several meridional chains of triangles may be utilized in this way, as their prototype has been, by having latitude observations taken at certain of their stations to give meridional arcs; and the several longitudinal chains of triangles may also be utilized—in combination with the main lines of telegraph—by electro telegraphic determinations of differential longitudes to give arcs of parallel. When the stations of the triangulation which are resorted to for the astronomical observations are situated in localities where the normal to the surface coincides fairly with the corresponding normal to the earth's figure, the result is valuable as a contribution to geodesy; when the normal to the surface is sensibly deflected by local attraction, the result gives a measure of the deflection which is valuable as a contribution to geognosy.

Having regard to these circumstances, I moved the Government to supply the Trigonometrical Survey with the necessary instruments for the measurement of the supplemental astronomical arcs; and as officers became available on the gradual completion of the successive chains of triangles, I employed some of them in the required determinations of latitude and differential longitude. It so happened that about the same time geodesists in Europe began to recognize the advantages to science to be acquired by connecting the triangulations of the different nationalities together, and supplementing them with arcs of amplitude. The "International Geodetic Association for the Measurement of degrees in Europe," was formed in consequence, and it has been, and is still, actively employed in carrying out this object; in India, however, the triangulation was complete and connected throughout, so that only the astronomical amplitudes were wanting. They are still in progress, but already meridional chains, aggregating 1,840 miles in length, and lying to the west of the Great Arc, have been converted into meridional arcs; and the three longitudinal chains from Madras to Mangalore, from Bombay to Vizagapatam, and from Kurrachee *via* Calcutta to Chittagong, of which the aggregate length is 2,600 miles, have been converted into arcs of parallel. In the former the operations follow the meridional course of the chains of triangles; in the latter they follow the principal lines of the electric telegraph, which sometimes diverge greatly from the direction of the longitudinal chains of triangles, the two only intersecting at occasional points; the astronomical stations are therefore placed at trigonometrical points which may happen to be nearest the telegraph lines whether on the meridional or on the longitudinal chains, and their positions are invariably so selected as to form self-verificatory circuits which are usually of a triangular form, presenting three differential arcs of longitude; each of these arcs is measured independently as regards the astronomical work—though, for the third arc, there is usually no independent telegraph line, but only a coupling of the lines for the first and second arcs—and this has been proved to give such an excellent check on the accuracy of the operations that it is not too much to say that no telegraphic longitude operations are entirely reliable which have not been verified in some such manner.

Through the courtesy of Colonel Stotherd, Director-General of the Ordnance Survey, I am enabled to exhibit two charts, one of the triangulation of India, the other of that of Europe, which have recently been enlarged to the same scale in the Ordnance Survey Office at Southampton for purposes of comparison. The first is taken from the official chart of the Indian Survey, and shows the great meridional and longitudinal chains and Lambton's network of principal triangles, the positions of the base lines measured with the Colby apparatus, the latitude and the differential longitude stations, the triangular circuits of the longitudinal arcs, the stations of the pendulum, and the tidal operations which will be noticed presently, and the secondary triangulations to fix the peaks of the Himalayan and Sulimani ranges, and the positions of Bangkok in Siam, and Kandahar in Afghanistan, the extreme eastern and western points yet reached. The chart of the European triangulation has been enlarged from one published by the International Geodetic Association of Europe; in it special prominence is given to the Russian meridional arc, which extends from the Danube to the Arctic Ocean, and is 25° 20′ in length, and to the combined English and French meridional arc, 22° 10′ in length, which extends from the Balearic Island of Formentera in the Mediterranean, to Saxavord in the Shetland Islands. The aggregate length of the meridional arcs already completed in India is about equal to that of the English, French, and Russian arcs combined; but the longest in India is about 1½° shorter than the Russian. As regards longitudinal arcs, I believe the two which were first measured in India, and were employed shortly afterwards by Colonel Clarke in his last investigation of the figure of the earth, are the only ones which have as yet been deemed sufficiently accurate to be made use of in such investigations, though arcs of much greater length have been measured in Europe. It would be interesting, if time permitted, to set forth the salient points of divergence between the systems of the Indian and the European surveys; I will only mention that in the southern part of the Russian arc, for a space of about 8° from the Duna to the Dneister, a vast plain, covered with immense and almost impenetrable forests, presented great obstacles to the prosecution of the work; the difficulty was overcome by the erection of a large number of lofty stations of observation, wooden scaffoldings which were 120, and even as much as 146, feet high, to overlook the forests. In Indian forests, as the Terai, on the borders between British and Nepalese territories, the stations were rarely raised to a greater height than 30 feet, or just sufficient to overtop the curvature, and all trees and other obstacles were cleared away on the lines between them; this was found the most expeditious and economical process. The stations were very substantial, with a central masonry pillar, for the support of a great theodolite, which was isolated from the surrounding platform for the support of the observer. The lofty Russian scaffoldings only sufficed for small theodolites, and they were so liable to shake and vibration that the theodolites had to be fitted with two telescopes to be pointed simultaneously by two observers at the pair of stations, the angle between which was being measured.

All the modern geodetic data of the Indian survey that were available up to the year 1880 were utilized by Colonel A. R. Clarke, C. B. of the Ordnance Survey, in the last of the very valuable investigations of the figure of the earth which he has undertaken from time to time. It will be obvious that new data tend to modify in some degree the conclusions derived from previous data, for the figure of so large a globe as our earth is not to be exactly determined from measurements carried over a few narrow belts of its superficies. Thus, thirty years ago it was inferred that the equator was sensibly elliptic—and not circular, as had been generally assumed —with its major axis in longitude 15° 34′ east of Greenwich, but later investigations indicate a far smaller ellipticity, and place the major axis in west longitude 8° 15′. More significant evidence of the influence of new facts of observation in modifying previous conclusions is furnished by the French national standard of length, the meter, which was fixed at the ten-millionth part of the length of the earth's meridional quadrant, as deduced from the best geodetic data available up to the end of the last century; but it is now found to be nearly $\frac{1}{5000}$th part less than the magnitude which it is supposed to represent, the difference being about a hundred times greater than what would now be considered an allowable error in an important national standard of measure.

The Indian survey has also made valuable contributions to geodesy and geognosy in an elaborate series of pendulum observations for determining variations of gravity, which throws light both on the grand variation from the poles to the equator that governs the ellipticity, and on the local and irregular variations depending on the constitution of the interior of the earth's crust. They were commenced in 1865 by Captain J. P. Basevi, on the recommendation of Gen. Sabine and the Council of the Royal Society, with two pendulums, one of which the General had swung in his notable operations which extend from a little below the equator to within 10° of the pole. Captain Basevi had nearly completed the operations in India, and had taken swings at a number of the stations of the Great Arc, and at various other points near mountain ranges and coast lines, when he died of exposure in 1871 at a station on the high table-lands of the Himalayas, while investigating the force of gravity under mountain ranges. Major Heaviside swung the pendulums at the remaining Indian stations, then at Aden and Ismailia on the way back to England, and finally at the base station, the Kew Observatory. Afterwards they and a third pendulum were swung at Kew and Greenwich by Lieutenant-Colonel Herschel, who took all three to America, swung them at Washington, and then handed them over to officers of the United States Coast Survey, by whom they have been swung at San Francisco, Auckland, Sydney, Singapore, and in Japan.

The pendulum operations in India have been successful in removing from the geodetic operations the reproach which had latterly been cast on them, that their value has become much diminished since the discovery that the attraction of the Himalayan mountains is so much greater than had previously been suspected, that it may have materially deflected the plumb-line at a large number of the astronomical stations of the Great Arc, and injuriously influenced the observations. Everest considered the effects of the Himalayan attraction to be immaterial at any distance exceeding sixty miles from the feet of the mountains; but in his days the full extent and elevation of the mountain masses was unknown, and their magnitude was greatly underestimated. Afterwards, when the magnitude became better known, Archdeacon Pratt, of Calcutta, a mathematician of great eminence, calculated that they would materially attract the plumb-line at points many hundred miles distant; he also found that everywhere between the Himalayas and the ocean, the excess of density of the land of the continent, as compared with the water of the ocean, would combine with the Himalayan attraction and increase the deflection of the plumb-line northwards, towards the great mountain ranges, and that under the joint influence of the Himalayas and the ocean the level of the sea at Kurrachee would be raised 560 feet above the level at Cape Comorin.

But, as a matter of fact, the Indian arc gave a value of the earth's ellipticity which agreed sufficiently closely with the value derived from the arcs measured in all other quarters of the globe, to show that it could not have been largely distorted by deflections of the plumb-line; thus, it appeared that whereas Everest might have slightly underestimated the Himalayan attraction, Pratt must have greatly overestimated it. His calculations were, however, based on reliable data, and were indubitably correct. For some time the contradiction remained unexplained, but eventually Sir George Airy put forward the hypothesis that the influence of the Himalayan masses must be counteracted by some compensatory disposition of the matter of the earth's crust immediately below them, and in which they are rooted; he suggested that the bases of the mountains had sunk to some depth into a fluid lava which he conceived to exist below the earth's crust, and that the sinking had caused a displacement of dense matter by lighter matter below, which would tend to compensate for the excess of matter above. Now, Pratt's calculations had reference only to the visible mountain and oceanic masses, and their attractive influence—the former positive, the latter negative—in a horizontal direction; he had no data for investigating the density of the crust of the earth below either the mountains, on the one hand, or the bed of the ocean, on the other. The pendulum observations furnished the first direct measures of the vertical force of gravity in different localities which were obtained and these measures revealed two broad facts regarding the disposition of the invisible matter below: first, that the force of gravity diminishes as the mountains are approached, and is very much less on the summit of the highly-elevated Himalayan table-lands than can be accounted for otherwise than by a deficiency of matter below; secondly, that it increases as the ocean is approached, and is greater on islands than can be accounted for otherwise than by an excess of matter below. Assuming gravity to be normal on the coast lines, the mean observed increase at the island stations was such as to cause a seconds pendulum to gain three seconds daily, and the mean observed decrease in the interior of the Continent would have caused the pendulum to lose 2½ seconds daily at stations averaging 1,200 feet above the sea level, 5 seconds at 3,800 feet, and about 22 seconds at 15,400 feet—the highest elevation reached—in excess of the normal loss of rate due to height above the sea.

Pratt was strongly opposed to the hypothesis of a substratum, or magma, of fluid igneus rock beneath the mountains; he assumed the earth to be solid throughout, and regarded the mountains as an expansion of the invisible matter below, which thus becomes attenuated and lighter than it is under regions of less elevation, and more particularly in the depressions and contractions below the bed of the ocean. And certainly we seem to have more reason to conclude that the mountains emanate from the subjacent matter of the earth's crust than that they are as wholly independent of it as if they were formed of stuff shot from passing meteors and asteroids; any severance of continuity and association between the visible above and the invisible below, appears, on the face of it, to be decidedly improbable.

The hypothesis of sub-continental attenuation and sub-oceanic condensation of matter, is supported by the two arcs of longitude on the parallels of Madras and Bombay; for, at the extreme points of these arcs, which are situated on the opposite coast lines, the horizontal attraction has been found to be not landwards, as might have been anticipated, but seawards, showing that the deficient density of the sea, as compared with the land, is more than compensated by the greater density of the matter under the ocean than of that under the land.

While on the subject of the constitution of the earth's crust, I may draw attention to the circumstance that the tidal observations which have been carried on at a number of points on the coasts of India, as a part of the operations of the Survey, tend to show that the earth is solid to its core, and that the geological hypothesis of a fluid interior in untenable. They have been analyzed by Prof. G. H. Darwin, with a view to the determination of a numerical estimate of the rigidity of the earth, and he has ascertained that while there is some evidence of a tidal yielding of the earth's mass, that yielding is certainly small, and the effective rigidity is very considerable, not so great as that of steel, as was at first surmised, but sufficient to afford an important confirmation of the justice of Sir William Thomson's conclusion as to the great rigidity.

The Indian pendulum observations have been employed by Colonel Clarke, in combination with those taken in other parts of the globe, to determine the earth's ellipticity. Formerly there was wont to be a material difference between the ellipticities which were respectively derived from pendulum observations and direct geodetic measurements, the former being somewhat greater than $\frac{1}{290}$, the latter somewhat less than $\frac{1}{300}$; but as new and more exact data became available, the values derived from these two essentially independent sources became more and more accordant, and they now nearly agree in the value $\frac{1}{293}$.

As a part of the pendulum operations, a determination of the length of the seconds pendulum was made at Kew by Major Heaviside, with the pendulum which had been employed for the same purpose by Kater early in the present century, when leading men of science in England believed that in the event of the national standard yard being destroyed or lost, the length might be reproduced at any time with the aid of a reversible pendulum. In consequence of this belief, an Act of Parliament was passed in 1824 which defined the relations between the imperial and the seconds pendulum, the length of the former being to that of the latter—swung in the latitude of London, in a vacuum, and at the level of the sea—in the proportion of 36 inches to 39.1393 inches. Thus, while the French took for their unit of length the ten millionth part of the earth's meridional quadrant, the English took the pendulum swinging seconds in the latitude of London. In case of loss, the yard is obviously recoverable more readily and inexpensively by reference to the pendulum than the meter by reference to the quadrant; it is also recoverable with greater accuracy; still the accuracy is not nearly what would now be deemed indispensable for the determination of a national standard of length, and it is now generally admitted that every pendulum has certain latent defects, the influence of which cannot be exactly ascertained. Thus, the instrument cannot be relied on as a suitable one for determinations of absolute length; but, on the other hand, so long as its condition remains unaltered, it is the most reliable instrument yet discovered for differential determinations of the variations of gravity. In truth, however, the pendulum is a very wearisome instrument to employ even for this purpose, for it has to be swung many days, and with constant care and attention to give a single satisfactory determination; thus, if such a thing can be invented and perfected as a good differential gravity meter, light and portable, with which satisfactory results can be obtained in a few hours, instead of many days, the boon to science will be very great.

The trigonometrical operations fix with extreme accuracy two of the co-ordinates —the latitude and longitude—which define the positions of the principal stations; but the third co-ordinate, the height, is not susceptible of being determined by such operations with anything like the same degree of accuracy, because of the variations of refraction to which rays of light passing through the lower strata of the atmosphere are liable, as the temperature of the surface of the ground changes in the course of the day. In the plains the apparent height of a station ten to twelve miles from the observer has been found to be upwards of 100 feet greater in the cool of the night than in the heat of the day, the refraction being always positive when the lower atmospheric strata are chilled and laden with dew, and negative when they are rarified by the heat radiated from the surface of the ground. At hill stations the rays of light usually pass high above the surface of the ground, and the diurnal variations of refraction are comparatively immaterial, and very good results are obtained by the expedient of taking the vertical observations between reciprocating stations at the same hour of the day, and as nearly as possible at the time of minimum refraction; but in the plains this expedient does not usually suffice to give reliable results. The hill ranges of central and those of northern India are separated by a broad belt of plains, which embraces the greater portion of Sind, the Punjab, Rajputana, and the valley of the Ganges, and is crossed by a very large number of the principal chains of triangles, on the lines where the chart shows stretches of comparatively small triangles, which are, in most instances, of considerable length. Thus it became necessary to run lines of spirit levels over these plains, from sea to sea, to check the trigonometrical heights. The opportunity was taken advantage of to connect all the levels which had been executed for irrigation and other public works, and reduce them to a common datum; and eventually lines of level were carried along the coast and from sea to sea to connect the tidal stations. The aggregate length of the standard lines of level executed up to the present time is nearly 10,000 miles, and an extensive series of charts of the levels derived from other departments of the public service and reduced to the survey datum has already been published.

The survey datum which has been adopted for all heights, whether deduced trigonometrically or by spirit leveling, is the mean sea level as determined, either for initiation or verification, by tidal observations at several points on the coast lines. At first the observations were restricted to what was necessary for the requirements of the survey, and their duration was limited to a lunar month at each station. In 1872 more exact determinations were called for, to ascertain whether gradual changes in the relative level of land and sea were taking place at the head of the Gulf of Cutch, as had been surmised by the geological surveyors, and observations were taken for over a year at three tidal stations on the coasts of the gulf, to be repeated hereafter when a sufficient period had elapsed to permit of a measurable change of level having taken place. Finally, in 1875, the Government intimated that, as "the great scientific advantages of a systematic record of tidal observations on Indian coasts had been frequently urged and admitted," such observations should be taken at all the principal ports and at such points on the coast lines as were best suited for investigations of the laws of the tides. In accordance with these instructions, five years' observations have been made at several points, and new stations are taken up as the operations at the first ones are completed.

The initiation of the latter and more elaborate operations is due, in great measure, to the recommendations of the Tidal Committee of the British Association, of which Sir William Thomson was President. The tidal observations have been treated by the method of harmonic analysis advocated by the committee. The constants for amplitude and epoch are determined for every tidal component, both of long and of short periods, and, with their aid, tide-tables are now prepared and published annually for each of the principal ports; and, further, it is with them that Professor G. H. Darwin made the investigation of the effective rigidity of the earth, which I have already mentioned. The very remarkable waves which were caused by the earthquake on December 31, 1881, in the Bay of Bengal, and by the notable volcanic eruptions in the Island of Krakatoa and the Straits of Sunda, on August 27 and 28, 1883, were registered at several of the tidal stations, and thus valuable evidence has been furnished of the velocities of both the earth-wave and the ocean-wave which are generated by such disturbances of the ordinarily quiescent condition of the earth's crust.

I must not close this account of the non-graphical, or more purely scientific, operations of the great Trigonometrical Survey of India without saying something of the officers who were employed thereon, under the successive superintendence of Everest, Waugh, and myself. A considerable majority were military, from all branches of the army—the cavalry and infantry, as well as the corps of engineers and artillery; the remainder were civilians, mostly promoted from the subordinate grades. Prominent shares in the operations were taken by Lieutenant Renny, Bengal Engineers, afterwards well known in this neighborhood as Colonel Renny Tailyour, of Borrowfield, in Forfarshire, of whom and his contemporary, Lieutenant Waugh, Everest retiring, reported in terms of the highest commendation; by Reginald Walker, of the Bengal Engineers, George Logan, George Shelverton, and Henry Beverley, all of whom fell victims to jungle fever; by Strange, F. R. S., of the Madras Cavalry, whose name is associated with the construction of the modern geodetic instruments of the Survey; by Jacob—afterwards Government Astronomer at Madras—Rivers and Haig, all of the Bombay Engineers; Tennant, C. I. E., F. R. S., Bengal Engineers, afterwards Master of the Mint in Calcutta; Montgomerie, F. R. S., of the Bengal Engineers, whose name is best remembered in connection with the Trans-Himalayan geographical operations; James Basevi, of the Bengal Engineers, who so sadly died of exposure while engaged on the pendulum operations in the higher

Himalayas; Branfill, of the Bengal Cavalry; Thuillier, Carter, Campbell, Trotter, Heaviside, Rogers, Hill, and Baird, F. R. S., all engineer officers; also Hennessey, C. I. E., F. R. S., M. A., Herschel, F. R. S., and Cole, M. A., whose names are intimately associated with the collateral mathematical investigations, and the final reduction of the principal triangulation.

The Trigonometrical Survey owes very much to the liberal and even generous support which it has invariably received from the Supreme Government, with the sanction and approval, first of the Directors of the East India Company, and afterwards of the Secretary of State for India. In times of war and financial embarrassment the scope of the operations has been curtailed, the establishments have been reduced, and some of the military officers sent to join the armies in the field; but, whatever the crisis, the operations have never been wholly suspended. Even during the troubles of 1857–58, following the mutiny of the native army, they were carried on in some parts of the country, though arrested in others; and the then Viceroy, Lord Canning, on receiving the reports of the progress of the operations during that eventful period, immediately acknowledged them to the Surveyor-General, Colonel Waugh, in a letter from which the following extract is taken:

"I cannot resist telling you at once with how much satisfaction I have seen these papers. It is a pleasure to turn from the troubles and anxieties with which India is still beset, and to find that a gigantic work, of permanent peaceful usefulness, and one which will assuredly take the highest rank as a work of scientific labor and skill, has been steadily and rapidly progressing through all the turmoil of the last two years."

The operations have been uninfluenced by changes of *personnel* in the administration of the Indian Empire, as Governor-Generals and Viceroys succeeded each other, but have met with uniform and consistent support and encouragement. It may well be doubted whether any similar undertaking, in any other part of the world, has been equally favored and as munificently maintained.

In conclusion, I must state that I have purposely said nothing of the graphical operations executed in the Trigonometrical and other branches of the Survey of India, because they are more generally known, their results appear in maps which speak for themselves, and time would not permit of my ttempting to describe them also. They comprise, *first*, the general topography of all India, mostly on the standard scale of 1 inch to the mile; *secondly*, geographical surveys and explorations of regions beyond the British frontier, notably such as are being carried on at the present time on the Russo-Afghan frontier by Major Holdich and other officers of the Survey; *thirdly*, the so-called Revenue Survey of the British districts in the Bengal Presidency, which is simply a topographical survey on an enlarged scale—4 inches to the mile—showing the boundaries and areas of villages for fiscal requirements; and, *fourthly*, the Cadastral Survey of certain of the British districts in the Bengal Presidency, showing fields and the boundaries of all properties, on scales of 16 to 32 inches to the mile. There are also certain large-scale surveys of portions of British districts in the Madras and Bombay Presidencies, which, though undertaken originally for purely fiscal purposes, by revenue and settlement officers working independently of the professional survey, have latterly been required to contribute their quota to the general topography of the country. And of late years a survey branch has been added to the Forest Department, to provide it with working maps constructed for its own requirements on a larger scale than the standard topographical scale, but on a trigonometrical basis, and in co-operation with the Survey Department. But this brief capitulation gives no sort of idea of the vast amount of valuable topographical and other work for the requirements of the local administrations and the public at large—always toilsome, often perilous—which has been accomplished, quite apart from and in quantity far exceeding the non-graphical and more purely scientific work which I have been describing. Its magnitude and variety are such that a mere list of the officers who have taken prominent shares in it, from first to last, would be too long to read to you. Three names, however, I must mention: *First*, that of General Sir

Henry Thuillier, who became Surveyor-General on the same day that I succeeded to the superintendence of the Great Trigonometrical Survey, and with whom I had the honor of co-operating for many years; under his administration a much larger amount of topography was executed than under any of his predecessors, and a great impetus was given to the lithographic, photographic, engraving, and other offices in which the maps of the survey are published; *secondly*, that of Colonel Sconce, who became Deputy Surveyor-General soon after my accession in 1878 to the Surveyor-Generalship, and with whom I was associated for some years, much to my gratification and advantage in various matters, but more particularly in the establishment of cadastral surveys on a professional basis at a moderate cost, to render them more generally feasible, which was a matter of the utmost importance for the administration of the more highly populated portions of the British provinces; and, *thirdly*, that of Lieut.-Colonel Waterhouse, who has for many years superintended the offices in which photography is employed, in combination with zincography and lithography for the speedy reproduction *en masse* of the maps of the Survey, and has done much to develop the art of photogravure, whereby drawings in brushwork and mezzotint may be reproduced with a degree of excellence rivaling the best copperplate engraving, and almost as speedily and cheaply as drawings ink pen and in work are reproduced by photo zincography.

Mr. Clements Markham's "Memoir on the Indian Surveys" gives the best account yet published of the several graphical surveys up to the year 1878. In that year the Trigonometrical, Topographical, and the Revenue branches, which up to that time had constituted three separate and almost independent departments, were amalgamated together into what is now officially designatad "the Survey of India." In the same year the chronicle so well commenced by Mr. Markham came to an end on his retirement from the India office—unfortunately, for it is a work of excellence in object and in execution, and most encouraging to Indian surveyors, who find their labors recorded in it with intelligent appreciation and kindly recognition.

LIQUID FUEL.

From "Iron."

The time-honored question of the utilization of hydro-carbons for steam-raising purposes has been once more brought prominently forward in this country by the practical application of a new system for effecting that object. This system is the invention of Mr. Percy F. Tarbutt, and it has been applied to the furnaces of an 800-ton steamship which has recently made a very satisfactory run from London to Leith and back. The success of this run, taken in conjunction with certain collateral circumstances to which we shall presently more fully refer, points to the possibility of the use of liquid fuel in the present connection becoming an accomplished fact at no distant period in this country. In other countries where the oil is a natural and plentiful product, its practical application for steam-raising purposes has long been common. In Great Britain, however, any success in adapting it to this use has generally been followed by an inordinate, and, therefore, prohibitory rise in the price of the fuel, which has extinguished the furnace and the hopes of the inventor at one and the same time. We have said that the question is a time-honored one, and, before proceeding to describe Mr. Tarbutt's method of solving it, it may be as well if we glance back at what has been attempted or accomplished in the past in utilizing liquid fuel. So long ago as 1830, Mr. H. Pinkus claimed to have used hydro-carbons in conjunction with streams of vapor for steam-raising purposes, and from that time down to the present, engineers and inventors have not, for any lengthened period, ceased to labor in the same direction. Richardson's petroleum furnace, as well as that of Bridges Adams, have both come under our personal observation in the past, and they were for many years under the constant notice of the officials in Woolwich Dockyard. In 1868 the Government permitted Wise, Field, and Aydon's system of using petroleum by the aid of an induced current to be applied to a marine boiler on board a steam yacht. The same system had also been previously applied to a Cornish boiler, at some large works in London, which we saw giving good results. The Admiralty also tried at Sheerness a somewhat similar plan, invented by Mr. S. E. Crow, but, as in the Woolwich trials, without anything practical resulting. In the same year, which appears to have been marked by a sudden outbreak of inventive activity in connection with the subject of liquid fuel, Dorsett's petroleum furnace was fitted under the boiler of the steamship *Retriever*, of 90 horse-power and 500 tons burden, and some very successful runs were made with her, at which we were present. The excellent results obtained in the *Retriever* led Mr. Dorsett to apply the system to re-heating furnaces, and a furnace of this class was fitted up at the works of Messrs. Camroux & Co., of Deptford, and we believe, successfully run for a considerable length of time.

In the same year corresponding attention was paid to the subject of liquid fuel in France, one system tried there being that of M. Verstraet, a chemist, in the development of whose invention M. Sainte-Claire-Deville took an active part. The Emperor of the French also took a personal interest in the question of liquid fuel. M. Verstraet's system, which consisted in conducting, or rather inducting, the gases of the oil to the furnace by a current of air was applied to a locomotive on the Eastern of France Railway, and upon the occasion of the Emperor visiting the camp at Chalons, the train was drawn by the engine thus fitted. His Majesty rode on the footplate of the engine in company with MM. Sauvage, Dieudonne, and Sainte-Claire-Deville. In the same year, His Majesty also made a run in the *Puebla*, a steamer in which mineral oil was employed to raise the steam for the engines. In America, liquid fuel has been used both on locomotives and in steamers, at one time, we believe, to a considerable extent. But, notwithstanding the advantages offered in the way of cheap and plenteous liquid fuel, it would seem to have but a very limited application in practice for steam-raising purposes. In Russia, a very different condition of matters exists, inasmuch as for several years past petroleum refuse has been used as fuel in the locomotives on the Grazi and Tsaritsin Railway in South-east Russia, the first trials on that line having been made in 1874. Besides this, numbers of steamers are now running on the Caspian Sea which are using liquid fuel. As far as the practical adoption of the principle in Great Britain and France has gone nothing further appears to have resulted. The reason for this we believe to be that which we have already indicated, namely, that directly a demand was created for the class of liquid fuel used, and which at that time was a drug on the market, the prices went up to a prohibitive extent. But we appear to be within a measurable distance of a change for the better in this respect, inasmuch as—and this is the collateral circumstance to which we have already alluded—in consequence of the comparative scarcity and dearness of petroleum in this country, a fleet of large tank steamers is now being built by the Russian Black Sea Navigation Company to bring regular supplies of the Russian oil to Europe in bulk. Given constant and adequate supplies, and an efficient means of utilizing them in boiler and other furnaces, and the question of liquid fuel would appear to be solved, other things, of course, being equal.

To bring the question of liquid fuel down to the present time, we must now refer to the system of Mr. Tarbutt (of the firm of Tarbutt & Quentin, of 75 Lombard Street, London), which we recently inspected as fitted on board the steamship *Himalaya*. This vessel is a trader of 100 horse-power, nominal, and 800 tons burden. She is 210 feet long, with 28 feet beam, and is fitted with compound engines, driving a screw propeller. The boilers have three furnaces, each of which has an openwork firebrick lining on the principle of the Siemens regenerative system. At the end of each furnace is a fire-brick baffle, having an aperture through which the heat passes to the tubes from the furnace, or, as it may more correctly be called, the combustion chamber. In this chamber is a coil of iron pipe, one end of which is connected with the steam space of the boiler, and the other opens out at the door of the chamber. This coil is for the purpose of superheating steam taken from the boiler, and by which an induced current is set up, which carries the petroleum forward into the combustion chamber. In order to enable it to do this the petroleum nozzle is placed within the steam pipe at the opening where it delivers its jet, so that an annular space is formed, through which the steam rushes, and, combining with the small but regular flow of the oil, produces a large volume of flame within the chamber. The oil is stored in tanks on the main deck, whence it flows by gravity to the delivery nozzles at the furnaces. The whole apparatus is very simple, and easily adjustable. One important feature is that, in the event of oil not being obtainable at any port where fuel is required, the oil-burning fitting can be removed, and the fire-bars for burning coal be replaced in a very short time. Another important feature of the system, which we must not omit to mention, is the method of starting the furnace, which is effected by a very simple arrangement, whereby sufficient steam is quickly raised to start and maintain combustion until the steam pressure in the boiler is sufficient for that purpose. The *Himalaya* belongs to the Marahu Petroleum and Oil-produce Company, of Suffolk House, Cannon Street, London, and by them has been fitted with the apparatus we have described in order to practically and commercially test the system. She will, however, eventually be renamed the *Marahu*, after her owners, the Marahu Company. The coal-carrying capacity of this vessel is about 240 tons, and her consumption of this fuel is stated to be ten tons per day. She will now require to carry only 110 tons of oil, her consumption of liquid fuel being put at 4½ tons per day, thus giving a great increase of cargo capacity. It is intended to employ her for trading purposes along the coast of Brazil, where her supply of liquid fuel will be regularly obtained from the works of the company to which she belongs. We recently inspected the furnaces and oil equipment of the *Himalaya* while in dock, and witnessed a demonstration of the satisfactory working of the apparatus, combustion being nearly perfect, as evidenced by the very small amount of smoke that issued from the funnel. A fairly steady steam pressure of 55 lbs. per square inch was maintained, the steam, of course, being blown off as made. On her return journey from Leith, the *Himalaya* arrived several hours sooner than was expected, having made the quickest voyage ever performed by her, and this in spite of the circumstance that one of her propeller blades was broken off in a collision with a barge in port. It is stated that the vessel is very much under-boilered, but that with the liquid fuel she made more steam than she ever had made with coal.

Taking the circumstances of the case generally, including the attempt now being made by Russian enterprise to secure a regular and full supply of oil to this country, it would appear as though the solution to the liquid-fuel problem was at hand. That solution would mean an enormous saving in our solid fuel, coal, whilst our steamships would be relieved of some 50 per cent. of their fuel weight, which could either be assigned to cargo, or, where long voyages had to be made, to a double supply of liquid fuel.

REPORTS OF ENGINEERING SOCIETIES.

Engineers' Club of Philadelphia—Record of Regular Meeting, November 21, 1885.—Past President Rudolph Hering in the chair.

The Secretary presented, for Mr. W. S. Church, a large number of photographs, tracing, pamphlets, and other documents, illustrating the design and progress of the New Croton Aqueduct, and read two communications from Mr. Church. He says: "The 'ground' through which the tunnel is advancing, is largely gneiss with considerable limestone, felspar, and occasional quartz seams. The dips are so vertical that much roof rock comes away. This trouble is increased by the too free use of high explosives near the perimeter of the vertical section, so that the area excavated runs from 25 to 50 per cent. in excess.

"A most careful system of measuring and recording just what is excavated is being carried out. A vertical dial, which the boys call 'The Sun Flower,' is set up every 10 ft., and oftener if necessary, and radial measurements taken to all the inequalities of the section; these measures are plotted on the diagrams, and the areas estimated with the planimeter

"The principal difficulty that the line has yet encountered, is the Gould Swamp It has finally been decided to under-run this in solid rock with a siphon, making a blow-off below grade, and draining by an adit out into the Hudson River.

"In Vol. V., No. 1, page 13, in a discussion of Mr. A. Harvey Tyson's paper on 'Pollution in Storage Reservoirs,' I notice that Mr. Charles G. Darrach says, 'I would call attention to the fact that in the proposed Quaker Bridge Dam for the New Croton Aqueduct no provision seems to have been made, as far as can be learned from published plans, for draining off the water from the lower levels. As this dam will be of almost unprecedented depth, the same trouble may be expected as in Baltimore and Reading, unless this precaution is taken.' The Club will observe, from the drawing sent, that this criticism is fully met, and that the big reservoir of the Croton will, when constructed according to present designs, have the best *circulation* of any reservoir in the world."

Mr. Jno. S. Elliott presented a paper on "Specifications as Affecting the Dimensions of Iron Railroad Bridges." As closely as harmonize theory and practice in bridge engineering, and notwithstanding the agreement amongst builders there still remain differences and inconsistencies in matters. Example given of two spans, built by Detroit Bridge Iron Co., one 154 ft., the other 162 ft., in length, the first has 30 per cent. more metal in it, showing to what extent different rolling load, requirements and dimension formulæ may affect metal amounts. The author reviewed some departures from the usual methods of distributing the load for purposes of calculating the strains, showing them to be unnecessary refinements. The subject of wind bracing was taken up, and one important principle involved in the dimensioning of the chord members for wind stresses shown to be applicable to double track through trusses—making a saving of between 15 and 20 per cent. in material. It is this: No addition to chord members for wind stresses is made, unless the combined wind and load stresses cause a strain in the member over and above a certain proportion of the maximum dead and live load stresses. In other words, as it is but seldom the case that all possible stresses combine, no addition to chord members will be made unless a certain strain limit is passed. The same principle should hold good for a double track through span, where any one of the two trusses but seldom is required to resist all possible attacking forces. Wohler's law with Launhardt's and Weyrauch's deductions then treated and examples given of variations in dimensions of existing bridges caused by using them. Economy to use these formulæ in long spans and to the best of the author's belief, the firm of Wilson Bros., members of the Club to be the first to use them in this country scientifically.

A discussion followed upon the paper of Mr. James Christie, upon the "Adaptation of Steel to Structural Work." Mr. Thos. M. Cleemann thought the use of steel instead of iron by engineers was dependant principally on the manufacturers producing a perfectly uniform and reliable product, which at present they do not seem to do. He thought that the advantage of using a cast metal was in favor of steel, by which struts could be made of a hollow circular section, requiring least material, and the punching of holes for fastening pieces together by riveting, which especially weakens steel of a high grade, could be dispensed with.

Mr. James Christie said in reply, that it was very improbable that struts would ever again be made directly from castings. Aside from the difficulty of maintaining a uniform thickness of metal, the cost of construction would be greater than by the present method of building up rolled material.

Professor Wm. H. Burr said the steel question presents itself to engineers under two entirely different aspects. The first involves the character of the metal *per se;* and the second is based upon the consideration of the influence of this metal on structural design. In the first place, although improvements in the uniformity of production can yet be made, steel makers, by either the Bessemer or open-hearth processes, are ready to work under any physical specifications affecting uniformity that may be demanded by the best engineering practice of the present time; and it may be safely asserted that increased uniformity will keep pace with any demand.

Unfortunately, however, there seems to be considerable diversity in the results of experiences with the many and varied shop manipulations necessary to the completion of the structural member. Mr. Christie tells us that in supplementing his most admirable tests on angle-iron struts, by those on composite riveted columns, he found the ultimate unit of stress in the latter essentially equivalent to that realized in the former. On the other hand, I am credibly informed by the chief inspector of an extensive railway system, that some full-sized high Bessemer steel latticed columns built for a large bridge failed, when tested to destruction, to give much, if any, excess over corresponding wrought iron columns These and other similar results suggest the possibility, or even probability, that the known sensitiveness of high steel demands a more extensive experimental experience with finished bridge members before the general use of such metal in columns can be considered satisfactory. Low structural steel of 60,000 to 65,000 pounds ultimate tensile resistance, is capable of any duty in the finished structure in the most satisfactory manner, and high steel of 80,000 to 90,000 pounds ultimate tensile resistance will eventually be equally reliable, but there are serious reasons for much care in its present use. The effect of the introduction of steel on structural design has not yet received the same consideration as that of constructive processes. With the increased working stresses allowed in steel, the coefficient of elasticity remains essentially the same as for wrought iron, with its lower allowable stresses. With the same design in both metals, the result is an increase of strains for steel in direct proportion to the unit stresses, and precisely the same proportional increase of deflections. The present and increasing requirements for rapidly moving loads make this a very serions aspect of the question, and give rise to a corresponding modification of design, so that proper stiffness as well as strength may be maintained. A comparison of the deflections of the Niagara and St. John's cantilevers, shows very clearly the effect of a constant coefficient of elasticity with an increased working stress. The principal dimensions of these strnctures are sufficiently near in value to afford a very interesting comparison. The greatest deflection of the Niagara Bridge, with its high steel compression members, with working stresses that cannot be far from 9,000 to 10,000 pounds, in combination with wrought iron tension members, was $7\frac{5}{16}$ inches; while that of the St. John's Bridge, with all members of about 60,000 pound steel and corresponding working stresses, was 4 inches. A proper allowance for the compression of the steel piers of the former leaves a remaining difference of over 2 inches Again, the effect of alternate stresses of opposite kinds on the design of steel members, is still a matter in almost a purely conventional state. The experiments of Weyrauch and Spargenberg are of the right kind, and constitnte a long step in the right direction ; but it must be borne in mind that these experimenters treated specimens and not structnral members. The ultimate physical condition of steel furnishes strong reasons for believing that its fatigue under compression will be considerably less than that of wrought iron.

Mr. George S. Strong presented an illustrated description of Rack Rail Appliances for railroads with very heavy grades.

Mr. J. Foster Crowell presented an illustrated paper upon Masonry Arches, treating mathematically the determination of dimensions of vonssoirs in difficnlt cases, and giving the result of his experience as to methods of withdrawing centers.

Mr. A. R. Roberts exhibited an appliance for fastening the Floor Timbers of Highway Bridges to the iron I-beams of the floor system. It consists of a piece of flat wrought iron cut from the ends toward the middle, the divided portions being bent at right angles to the piece, so that one opposite pair, after being ragged, can be driven in the wood, and the other pair bent under the flange of the iron beam.

Mr Kenry G. Morris introduced Mr. P. Oestburg, who exhibited specimens of and described the Mitis Metal Castings, which are made from wrought iron, and have a very high dnctility.

Mr. Wm. H Dechant presented a description of a Movable Dam and Caisson Operating Trnck, illustrated by a small model and photolithograph plates. He claims a nnmber of advantages in the system over the French or Chanoine system of movable dam, constructed by the United States Government at Davis' Island, below Pittsburgh, namely—a wicket of more simple construction, having a less number of wearing parts, and more positive action; less liability of being damaged by ice, snags, or any other body passing over them when down ; a simple appliance to throw the wickets down either separately or collectively; a caisson operating truck, to enable one wicket, or a certain number of them, to be quickly and effectually enclosed from the water above the dam, to allow repairs to be made, and also to enable the attendants to get immediately over the wickets and dam, so as to make careful examinations, and be in a positive position to raise the wickets, making it practicable, wherever necessary, to use steam power to operate the dam, instead of depending upon manual labor. The system also applies to flush strips on top of permanent dams, and they are in practical use on several of the dams on the Schuylkill Navigation; where the flush strips from 10 to 18 inches in height are used, they are operated directly by a man walking out along the comb of the dam, one man being able to raise or lower such a wicket 10 feet long with ease.

American Society of Civil Engineers—November 4th, 1885.—Vice-President G. S Greene, Jr., in the chair.

The following candidates were elected as members: Edward Sherman Gould, Yonkers, N. Y.; Benjamin Dwight Green, Oswego, N. Y.; Simpson Clark Heald, Worcester, Mass.; Thomas Franklin Richardson, El Paso, Texas; and as Fellow of the Society, Coddington Meyer, New York City.

The following amendment to the by-laws was regularly proposed :

To amend section 24, 5th clause, by substituting the word "December" for the word "November."

The Board of Direction was requested to issue a circnlar calling the attention of members to the desirability of adding to the number of junior members, and of exercising their personal inflnence with young men towards inducing them to make application in the ordinary way for jnnior membership.

A paper read by Mr F. Collingwood, M. Am. Soc. C. E., on "The Behavior of Cement Mortars under Various Contingencies of Use, with a Brief Discussion of Several Tests," was read. This paper calls attention to the desirability of securing observations upon the expansion and contraction of mortars when setting, and also of the compression at various ages under loads up to disintegration, at successive periods, both with pure cement, with various mixtnres of sand, with concrete and with lime mortars, and also, in addition, to make observations of the same nature upon various building materials. Attention was also called to the importance of measuring actual compressions in walls and masses of masonry, and also as to the setting of mortars if placed wet, and the best method under snch circumstances. Sнggestion were made as to desirable methods of securing these observations. Changes in dimensions of masonry by changes of temperature were also referred to. This general subject, in its various relations, will be considered by a committee, which has been appointed in pursuance of the action at the last annual meeting.

November 18th, 1885—Vice-President G. S. Greene, Jr., in the chair.

Discussions were presented on "Wind Strains in Bridges," on "Formulæ for the Weight of Iron and Steel Railway Bridges," on "Canals and Railways," "Ship Canals and Ship Railways."

An ingenious instrument for the accurate drawing of curves for railways and other purposes was exhibited and explained by Mr. A. Marischal, C. E. In connection with the work of the Committee on Uniform Standard Time, a new clock-dial was exhibited. The arrangement of this dial is such that, by a simple attachment, the figures representing the hours are automatically changed at the proper times, so that they represent the morning and afternoon hours consecutively.

St. Louis Engineers' Club—November 18, 1885.—Executive Committee recommended that the meetings be held on the first and third Wednesdays of each month during the session. On motion the recommendation was adopted.

The Secretary then read a programme for the Winter:—Dec. 2—C. M. Woodward, "Theory of Ammonia Refrigerators;" Dec. 16—Thos. J. Whitman, History of the St. Louis Water Works;" Jan. 6—J. A. Seddon, "Cross Sections of Uniform Flow in River Physics;" Jan. 20—P. M. Bruner, "The Use of Hydraulic Cements;" Feb. 3—Chas. C. Brown; Feb. 17—Chas. W. Melcher, "The Theory of the Sustaining Power of an Air Jet;" March 3—Robert E. McMath, "The Future drainage of St. Louis;" March 17—A. P. Man, "The Determination of Openings for Bridges and Culverts;" April 7—W. Paul Gerhardt, "Disposal of Household Waste;" April 21—Geo. H. Pegram; May 5—S. Bent Russel, "Water Supply for Fire Service;" May 19—W. H. Allderdice; June 2—Report of Committee on Smoke Prevention.

Prof. J. B. Johnson read a paper on the Solar Azimuths by Transit Attachments and Base Line Measurements by the Steel Tape. General discussion followed.

To the Editor of Van Nostrand's Engineering Magazine:

Sir—The undersigned committee of the Engineers' Club, of St. Louis, would respectfully call your attention to the following action:

Whereas, The Engineers' Club, of St. Louis, did, on March 18, 1885, appoint a Committee to "Consider and report on the best means of improving the status of civil engineers in the service of the general government," and

Whereas, Said committee, after due deliberation, decided that this subject was not of sufficient general interest or importance to justify the Club in initiating or supporting a movement tending to simply legislate in the interest of a certain class, and

Whereas, The committee, in accordance with these views, reported to the Club, on May 13, 1885, that it "regrets to see the discussion of the subject turning aside from the broad question of creating an organization for the conduct of public works." And, furthermore, that "to this question, personal matters, past, present, or future, the value of the different schools and modes of training, or the honesty and truthfulness inculcated through certain associations, are alike foreign. There seems, therefore, to be need for conservative influence lest the utterances of individuals be taken as expressing the views and wishes of the engineering profession, and lest a discussion of a pure question of public policy degenerate into a controversy about matters of no consequence." And

Whereas, The committee was continued to consider this broader question and make an effort, through "correspondence and conference" with other societies, to reach some common ground of action ultimately terminating in a convention to formulate a plan for creating an organization to conduct our public works, and to consider all questions relating thereto. Therefore be it

Resolved, That this committee does not deem it expedient to send a representative to the convention called to meet in Cleveland for the purpose of promoting class legislation, a matter foreign to the declared purposes for which this committee was continued.

Resolved That copies of these resolutions be furnished the several engineering societies of the country.

Robert. E McMath,
J. A. Ockerson,
J. B. Johnson,
H. S. Pritchett,
Committee.

St. Louis, Mo. Nov. 19, 1885.

ENGINEERING NOTES.

Ancient Tunnels and Arches.—Mr. Baker in his address to the British Association, said: "I have no doubt that as able and enterprising engineers existed prior to the age of steam and steel as exist now, and their work was as beneficial to mankind, though different in direction. In the important matter of water supply to towns, indeed, I doubt whether, having reference to facility of execution, even greater works were not done 2,000 years ago than now. Herodotus speaks of a tunnel 8 ft. square, and nearly a mile long, driven through a mountain in order to supply the city of Samos with water; and his statement, though long doubted, was verified in 1882 through the abbot of a neighboring cloister accidentally unearthing some stone slabs.

The German Archæological Society sent out Ernst Fabricius to make a complete survey of the work, and the record reads like that of a modern engineering undertaking. Thus, from a covered reservoir in the hills proceeded an arched conduit about 1,000 yards long, partly driven as a tunnel and partly executed on the "cut and cover" system adopted on the London underground railway. The tunnel proper, more than 1,100 yards in length, was hewn by hammer and chisel through the solid limestone rock. It was driven from the two ends like the great Alpine tunnels, without intermediate shafts, and the engineers of 2,400 years ago might well be congratulated for getting only some dozen feet out of level and little more out of line. From the lower end of the tunnel branches were constructed to supply the city mains and fountains, and the explorers found ventilating shafts and side entrances, earthenware socket-pipes, with cement joints, and other interesting details connected with the water supply of towns.

In the matter of masonry bridges, as great works were undertaken some centuries ago as in recent times. Sir John Rennie stated, in his presidential address at the Institute of Civil Engineers, that the bridge across the Dee at Chester was the "largest stone arch on record." That is not so. The Dee Bridge consists of a single segmental arch 200 ft. span and 42 ft. rise; but across the Adda, in Northern Italy, was built, in the year 1377—more than 500 years ago—a similar segmental arch bridge of no less than 237 ft. span and 68 ft. rise. Ferario not long since published an account of this, for the period, colossal work, from which it would appear that its life was but thirty-nine years, the bridge having been destroyed for military reasons on December 21, 1416. I believe our American cousins claim to have built the biggest existing stone arch bridge in the world—that across the Cabin Johns Creek; but the span, after all, is only 215 ft., or 10 per cent. smaller than the 500-year-old bridge. In timber bridges, doubtless, the Americans will ever head the list, for the bridge of 340 ft. span built across the Schuylkill three-quarters of a century ago, will probably never be surpassed. Our ancestors were splendid workers in stone and timber, and if they had been in possession of an unlimited supply of iron and steel, I fear there would have been little left for modern bridge builders to originate.

IRON AND STEEL NOTES.

Silicon in Cast-iron.—Mr. Thomas Turner draws the following conclusions from some recent experiments:

1. That a suitable small addition of silicon to cast-iron almost entirely free from silicon is capable of producing a considerable improvement in the mechanical properties of the metal

2. That in these experiments the maximum values are probably reached with the following amount of silicon:

		Per cent.
Crushing strength	about	0.80
Modulus of elasticity	"	1.00
Relative density (in mass)	"	1.00
Tensile strength	"	1.80
Softness and working qualities	"	2.50

3. That when general strength is required, the amount of silicon should not vary much from about 1.4 per cent.; but that when special softness and fluidity are desirable, about 2.5 per cent. may be added. Even in the latter case, however, any increase upon 3 per cent. must be dangerous.

These conclusions are only strictly true under the circumstances of the author's experiments, but he hopes shortly to bring forward evidence from independent investigations to support his results. The cause of these results is discussed. The author is decidedly of the opinion that the production of graphitic carbon is not the only cause of these differences, but that, in addition to the indirect effect owing to the production of gray iron, the suitable addition of silicon has a direct and beneficial influence upon the mechanical properties of the metal.

New Process of Steel Manufacture.—During the last few months works specially laid out for a new process of steel manufacture have been established at Manchester by Messrs. Bott & Hackney. This is termed a direct process, and may be described as a compromise between the Bessemer and the crucible processes. An important advantage secured is that baked moulds are dispensed with, the castings being made in green sand, so that the many severe internal strains caused by hard moulds at the time of cooling are avoided. The firm are thus enabled to produce steel castings which are practically free from blowholes and shrinkage, notwithstanding that metal out of one ladle can be indiscriminately poured into elevator bucket moulds less than $\frac{1}{8}$ inch thick, or into moulds for heavy crank shafts. We have had an opportunity of inspecting a number of steel castings produced by this process which, under any ordinary method, would probably be considered impossible of production. Amongst these were mule sickles which had been twisted cold, then forged and hardened that they could be ground to a razor edge; and, as an example of intricate work, a pulsometer, with all its internal parts, has been successfully cast, which is probably the first time that a complicated apparatus of this description has been produced in a steel casting. There were also pulsometer valves, which, after turning, were hardened, and complicated lever castings perfectly soft and ductile, which, after being machined, were free from any defects, and were afterward hardened at the point where friction would require a wearing surface. The process enables malleable steel castings to be produced which are perfectly sound and reliable, and which can be ersily forged, and hardened as required, either in oil or water.

RAILWAY NOTES

An Electrical Tramway Engine.—Trials of a new electrical tramway engine are shortly to be made at Stratford, the engine being the invention of Mr. C. P. Elieson. This engine has for some time past been tested and run at the works of the North Metropolitan Tramway Company, London, England. The electrical and mechanical part has been constructed by the Electric Locomotive and Power Company. It appears that an extension will shortly be made of the tramway from Stratford down the Ilford Road, and that arrangements will be made later on to work this portion entirely by electric engines. Meanwhile an engine of greater power is being constructed with the view of showing what can be done on a railway. It is stated that the maximum of speed developed in the engine under notice is about eight miles an hour, but, if necessary, an engine can be constructed to run as fast as may be required for all practical purposes. The power is derived from 50 cells, containing about 280 amperes, and the current used varies from about 60 amperes per hour at starting to about 35 amperes per hour when running.

An Engine's Great Record.—The Boston and Albany Railroad Company has been much interested in the performances of its locomotive passenger engine No. 137, which was built at the company's own shops. The following are the principal dimensions of the machine: Weight, 42 tons; cylinders, 18 by 22 in.; wheels, 68 in. diameter; boiler, 52 in. diameter; number of 2-in. tubes, 221; pressure, 160 lbs. This engine came out of shop April 23, 1883, and was taken in for general repairs October 30, 1885, having run daily 30 months and 7 days, or 921 days, making a total of 184,-723 miles. During this time the engine lost 12 days for repairs, and deducting this from the total number of days run, the average number of miles run per day is 203. No repairs were made until April 27, 1884, when the engine had run 78,812 miles. During portions of the months of April and June and the whole of the month of May, 1885, the engine ran 400 miles per day, making (with extra trips Sundays) 10,910 miles in May, and a total of 26,740 miles in the above-named months, an average of 8,913 miles per month. The 12 days lost and the causes were as follows: April, 1884, 1 day, broken equalizer; July, 1884, 4 days, tires turned, one broken driving-box replaced and throttle ground; July, 1884, 4½ days, broken piston-rod; May, 1885, ½ day, broken piston-rod, front cylinder-head and casing; September, 1885, 2 days, broken driving-box. The driving-boxes were of cast iron. Steel is now being used, and no more trouble is expected from that source.

ORDNANCE AND NAVAL.

The New Naval Guns.—A long series of experiments have been made by the Ordnance Committee with the new breech-loading guns now in course of issue for the latest of the ironclads, the Impérieuse and the Warrior, and much useful information has been gained respecting the behavior and requirements of breech loading steel ordnance, the action of modern gunpowders, and collateral subjects. The particular gun designed for this service is known as the 9.2-in., of 22 cwt., and fires a projectile of 380 lbs. The first thing required was to determine the description of powder best adapted to the size and construction of the gun, and next the quantity calculated to give the maximum impetus to the shot within the stipulated strain upon the gun, for which it was decided, as a preliminary condition, that the pressure should not exceed 17½ tons. Cocoa powders were chiefly employed in the trials, previous experiments having conclusively demonstrated the superiority of these, the brown, powders over all descriptions of the black gunpowders of the past, but a few rounds of prismatic and "rifle large grain" were fired by way of comparison. The methods of restraining the action of the powders by increase of moisture and other devices, which have been carefully studied of late years, were closely observed and recorded, the result being the production of a brown powder at the government works, Waltham Abbey, which seems to have given complete satisfaction. A favorable peculiarity of the brown powders is found to be the small quantity of smoke, and even this dissipates immediately, but these powders also have a liquid residue, which is so hot that it will fire gunpowder after 20 or 30 seconds' exposure, and, therefore, a cause of danger when the gun is reloaded, the accident on board the Canada last November having probably had some such origin. Such misfortunes are hereafter to be guarded against by cooling the gun, and using a close-fitting sponge to clean out the chamber. Rottweil and Westphalian cocoa powders have also been fired from the gun, and have exhibited similar qualities, and, after some defects in the rotating range of the projectiles had been amended, the gun was found to make excellent practice, the errors up to about 4,000 yards being remarkably slight. The breech action opened and closed with great facility, and without the necessity of using the ratchet gear, and the fitting of metal disks on the obturator answered admirably in saving the obturator and confining the powder gases. The carriage also is reported favorably upon by the committee, the recoils being regular and well under control. The new velocimeter invented by Colonel Sebert for registering recoils, pressure on buffers, and velocity of projectiles through the gun, was used in these trials with good effect. Two of these instruments have been purchased by the War Department, and are now employed in most of the experiments at Woolwich. The results of these observations, and frequent inspections of the experimental gun, have, however, shown that there is something yet to learn on the subject of steel artillery, for, after firing 166 rounds, mostly with excessive charges, the gun had to be relined, and a tendency is displayed by all the guns of similar manufacture to enlarge the bore. The increase is almost infinitesimal, and no gun has yet been rendered unserviceable from this cause, but it has been thought advisable, pending some further modifications in the gun or projectiles, that the firing of these heavy breechloaders shall be restricted as far as practicable to reduced charges It is doubted whether under the present conditions it will be possible to prolong the life of a gun without relining for more than 20 battering charges. It will seldom be necessary for the Impérieuse or the Warrior to fire the full charge, and the imposition of the rule will therefore be attended with no practical inconvenience. With half charges, which are usual at practice, the guns will remain undeteriorated from probably 1,000 rounds.

Messrs. Fredrich Krupp & Co. are at present, a correspondent says, manufacturing for the Italian Government four guns for a shore battery, which will be larger than any in the world. Each will weigh 120 tons, whilst a charge of 600 lbs. of gunpowder will be required for the firing of the projectile of one ton. The guaranteed range is five miles. The first of these monsters will be tested at Meppen on the firm's firing grounds, and transported to Italy on specially-built cars with sixteen axles, bridges and viaducts having to be strengthened in order to stand the weight.

An important addition has been made to the Swedish navy by the completion of the corvette Freja, built at the Kockum Engineering Works, Malmo. Her dimensions are—Length over all, 221 ft.: width, 41 ft.; and depth in the hold, 29 ft, She draws 19 ft. of water aft, and 16 ft. forward. The vessel is built throughout of soft, Swedish-Bessemer steel, and cased with a 3-in layer of teak and and a $2\frac{1}{2}$-in. one of fir. Her engines are of 2,000 horse-power, and manufactured in Sweden. She will be full-rigged, the masts of iron, having been made in England, and armed with ten 12-centimeter guns on the 'tween deck, and two 15-centimeter on the upper deck. The cost of the vessel is £85,000.

The following, from the *Railway Register*, is given by the *Journal of Railway Appliances* as "A St. Louis Bull." "Many iron boilers now in use have a record for efficient and continuous service extending over periods of time varying from a quarter to a third of a century. Iron can afford to stand by such a record as this. Are there any steel boilers with records that will compare favorably with these iron boilers?" As a comment, the *Journal* adds: "Show us the building of the present day," says the Hibernian orator, "which has lasted as long as those of antiquity." We may add that a quarter of a century of antiquity may be found in a steel fire-box in a boat on a Westmoreland lake, and described in *The Engineer*, August 13th, 1880.

BOOK NOTICES.

Publications Received.

Bulletins of the United States Geological Survey. Nos. 7 to 14.

No. 7.—A Catalogue of Geological Maps tive to North and South America.

No. 8.—Report of work done in Washington Laboratory during fiscal year 1883-4.

No. 9.—On Secondary Enlargements of Mineral Fragments in certain rocks.

No. 10.—On the Cambrian Faunas of North America.

No. 11.—On the Quaternary and Recent Mollusca of the Great Basin.

No. 12.—A Crystallographic study of the Thinolite of Lake Lahonton.

No. 13.—Boundaries of the United States, and of the several States and Territories, with a historical sketch of the territorial changes.

No. 14.—On the Physical Characteristics of the Iron-carburets, more particularly on the galvanic thermo-electric and magnetic properties of wrought iron and steel.

Washington: Government Printing Office.

The Prospector's Hand-book. By J. W. Anderson, M.A. London: Crosby, Lockwood & Co.

This is designed to be an aid to the out-door seeker after useful minerals. It can hardly be more than a suggestion, however, to a learner of right instincts, to prompt him to look up better sources of knowledge. The book is so small that everything is presented in too brief a manner to be of use to a novice in mineralogy or geology.

As a guide to the learner, directing him to the proper studies in acquiring skill in prospecting it may not be amiss.

Statistics of Hydraulic Works and Hydrology of England, Canada, Egypt and India. By Lewis d' A. Jackson. London: W. Thacker & Co.

This work contains valuable information regarding completed works. A large portion of it is in the form of tabulated statistics.

Rivers, canals, sewage irrigation, storage of water, with cost of construction, cost of maintenance, and productive value are the chief topics upon which the text of the book is based.

The work must prove particularly serviceable to engineers who undertake hydraulic works in either of the four specified countries, and of some value in any country where such works are in operation.

The book is well printed, but is without maps or diagrams.

A Primer of Orthographic Projection. By Major G. T. Plunkett. London: Sampson Low & Company.

This is a book for beginners in mechanical or architectural drawing, and will suit the wants of learners without teachers.

The diagrams are interspersed throughout the text, and the exercises are graded with skill. The treatise is an easy guide to the more advanced problems of descriptive geometry.

Mechanical Integrators. Van Nostrand's Science Series, No. 83. By Professor Henry S. H. Shaw. New York: D. Van Nostrand.

We are by no means certain that the title of this unique treatise will convey to the general reader an adequate idea of the scope of the work. To have called it an essay on planimeters would have only partially explained the author's design, but would not have proven to a great extent misleading.

Professor Shaw has given complete analyses of a large number of mechanical measuring machines; classifying them, describing their construction, and expounding the principle of action.

As a record of inventions of a peculiar kind, the work is very interesting, and as affording illustrations of mechanical solutions of complex computations, it is very instructive.

A Report on the Terminal Facilities for handling Freight by the Railroads entering the port of New York, especially of those Railroads having direct Western connections. Written and prepared for the *Railroad Gazette* by Gratz Mordecai. New York: *Railroad Gazette.*

A preliminary analysis of railroad work and accounts, and an investigation of the general subject of terminal work as it is illustrated at New York, closing with a general summary and conclusions derived from the information given, which consists of the detailed plans of, and the methods and approximate cost of operating, the several yards and freight houses, and including a partial industrial map of New York.

Octavo pamphlet, 68 pages text and 6 large lates. In flexible cloth, $1.50.

MISCELLANEOUS.

The proportion of organic matter present in the water supplied from the rivers to London during the month of October, though slightly in excess of that characterizing the supply of the past three months, was found to be very small, and exceptionally small in view of the year and of the swollen state of the river. The report of Mr. William Crookes, F. R. S., Dr. William Odling, and Dr. C. Meymott Tidy, states that the average proportion of organic carbon in the Thames-derived supply of the month was .128 part, and the maximum proportion in any one sample .145 part in 100,000 parts of the water, as against an average of .119 part, and a maximum of .146 part, for the preceding three months. In respect to state of aeration, and degree of freedom from color, and from any trace of turbidity, the quality of the water supplied by all the seven companies was unexceptionable.

Alloys of copper with cobalt are readily obtained by melting the two metals together under a flux of boric acid and wood charcoal, or by melting copper with an alloy of copper and cobalt, which is formed in the process of copper-smelting. The alloy used by M. Guillemin for this purpose had the composition Co, 48.28; Ni, 1.0; Cu, 50.26; Fe, 0.46=100. The alloys investigated contained from 1 to 6 per cent of cobalt. They have a red color, and a fine silky fracture, resembling that of pure copper. They have remarkable ductility, malleability and tenacity, and can be worked and rolled in the cold, but they cannot be tempered. They break under a tensile strain of from 25 to 36 kilos. per square millimeter, with an elongation of 28 to 15 per cent. An alloy containing 5 per cent. of cobalt, after forging and rolling, broke under a strain of 40 kilos. per square millimeter, with an elongation of 10 per cent. This particular alloy, the *Journal of the Chemical Society* says, is as malleable and as little liable to oxidation as copper, and is as ductile and tenacious as iron.

The supply of potable water in the Roman Campagna is one of the most urgent necessities in the improvement of this vast district. In order to provide one of the forts recently constructed for the defence of Rome with water, a boring was made by the military authorities for this purpose. This fort is situated near the tomb of Cecilia Metilla, on the Appian Way, about 2½ miles beyond the city walls, and at 70.30 meters—230.58 ft.—above the level of the sea. The results (Proc. Inst. C. E.) are most interesting, and show the advantage that may be derived from boring, as water, both for irrigation and potable uses, may be obtained by this means, for at a depth of 42.12 meters—138.15 ft.—or 28.18 meters—92.33 ft.—above the level of the sea, the first water-bearing stratum was found in the volcanic deposits, whilst a second was reached at a depth of 83.30 meters—273.22 ft—or 13 meters—42.64 ft.—below the level of the sea. in the quartertiary formation. The bore hole, which was 32 centimeters—12.6 in.—in diameter, was carried down to the depth of 90 meters—293.2 ft.—below the surface. Kind's percussion boring apparatus was used.

A new process for smoothing, polishing and fluting stone by machine power without the use of edge tools—the invention of Messrs. W. and T. Brindle, of Upholland, near Wigan—is now being developed by them in conjunction with Messrs. M. Powis, Bale & Co., of Appold Street, Finsbury. This process consists essentially in causing a revolving or reciprocating surface of iron to alternately bear against the surface of the stone to be worked, and then parted from it sufficiently to receive a layer of fresh sand and water between the rubbing surface and the rubbed. The rubbing surface is held down by a spring, but at intervals is raised from the rubbed surface by an eccentric cam. For fluting and similar operations a series of round bars of wrought iron are mounted in bearings and made to revolve; at the same time they are given a reciprocating movement. The block of stone to be fluted is placed on a trolly and run under the bars. Sand is sprinkled automatically over the bars or rollers as they revolve. For recessing, edge moulding, and similar purposes, rubbing disks are mounted on vertical spindles arranged to lift automatically for about half a revolution in every four. Several different types of machines are now in active operation. An advantage claimed for this process of working over hand labor with hammer and chisel, or machine work where cutters are forced into the stone, is that the surface of the stone is left perfectly smooth and "unstunned," and better capable of withstanding atmospheric influences. It is stated that fluted, recessed, and ornamental stone is now being sold by the inventors at 75 per cent. less than similar work produced by hand.

The Deepest Well.—Probably the deepest well in the world is one at Homewood, Pennsylvania, owned by Mr. George Westinghouse, jun. The average depth of the Homewood wells is about 1,850 ft. In the well now drilling everything found of the nature of gas or water at a depth of 2,000 ft. was cased off as unimportant, and the drill at present is said to be a little over 6,000 ft. below the surface, which would make it the deepest well in the world. A careful record is being kept, and portions of each formation encountered preserved. Since it would necessarily have to be a very prolific gas vein to justify such deep drilling, it is a difficult matter to conjecture the object that prompts such a work, unless it be purely to satisfy curiosity. There are in Washington County some wells drilled to a depth of 4,000 ft., and the only others, so far as known, approaching the depth reached by Mr. Westinghouse, is an artesian well in France, at which a depth of 5,000 ft. was reached.

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ON A CASE OF THE RAPID EXTERIOR CORROSION OF AN IRON WATER-MAIN.

By PHILIP D. BORDEN, Jr., and W. RIPLEY NICHOLS, Members of the Boston Society of Civil Engineers.

Journal of the Association of Engineering Societies.

I. Statement of the Case, by Mr. Borden.

During the summer of 1884, unmistakable signs of a leak presented themselves on the line of a six-inch main on the premises of the Fall River Iron Works, situated upon the shore of Mount Hope Bay, where the pressure upon the main was one hundred and twenty pounds per square inch.

On uncovering the pipe it was found that a change had taken place in the material of which it had been composed. The pipe was soft, being easily cut with a knife; was smooth and greasy, having the appearance of plumbago. Investigation proved that six pipes, or seventy-two feet, had been more or less affected. In some places the change extended nearly through the pipe, while at others, but a short distance from the first, the change was much less marked. The inner side of the pipe was perfect as when laid, the coating of "coal-tar varnish" remaining intact. The pipe had been in the ground about nine years.

Following is a section of the specifications relating to the quality of material of which the pipe should be composed, and there has never been any reason to suppose the pipe was not up to the standard as called for.

"*Quality of Metal.*—The metal shall be strong, tough and coarse-grained, with the carbon combined and not in the form of graphite, and as hard as the case will admit, but not too hard to be readily cut and drilled, and shall be re-melted from pigs of gray iron in a cupola or air-furnace, without any admixture of cinder iron or other inferior metal, and shall have a tensile strength of at least 16,000 pounds per square inch."

The corrosion has not been the same on all sides of the pipe, nor has the change followed any rule as to position. In some places it was most on the top of the pipe, as it lay in the ground, in others on one side, again on the other side, and in other places on the bottom.

Although the outside of the pipe was soft when taken out of the ground it has since become quite hard. On the premises of the iron works there are about 800 feet of pipe made and laid apparently under the same circumstances and subject to the same conditions, yet only this piece has undergone the change.

A sluice-way forming an outlet from Crab Pond to Mount Hope Bay, and one from works of the American Printing Company, through which are discharged the spent liquors from that establishment might appear to afford an explanation of the whole matter, but on noting that the pipe was taken from points not within one hundred feet of the sluice-way, while the pipe over the sluice-way is intact, it seems as if some other cause would have to be found.

At the northwesterly corner of the nail mill is a point used for at least twenty-five years by a large number of men as a urinal. At first it seemed probable that this might have had some effect upon the pipe, but it is found that a hydrant within five feet of the said corner was not affected. This leads us to suspect this is not the cause sought for.

When the wharf was built the wall was laid up and a portion back of it (shown by dotted lines on the plan (was not filled for several years. Into this pond hole the drip from the rolls of the iron works, and the drainage from the wheel pit of the engine was discharged until the hole was filled up, and it is even a question if it is not now allowed to discharge there, and find its way to the Bay through the filling, which it could readily do. The fact that this is where the pipe had undergone the greatest change leads us to look at this with some suspicion. The drip from the rolls would, of course, be warm. The main here is a "dead end," intended simply for fire-protection, consequently the water might remain therein some time without being renewed, and become quite warm, keeping the pipe in the best condition to be acted upon by salt water. It is conceded hereabout that warm salt water is damaging to cast iron, more especially if oil or other grease is present.

Some years since the condenser of an engine, so located that the tide reached it, was affected the same way, and it was then thought to have been caused by the combined action of heat and salt water. At that time it was stated that the wrought iron, though subjected to the same influences, was not affected.

The whole of this pipe is laid on made land, most of the filling being cinders, iron slag from puddling furnaces, and such other refuse as is usually found about an "iron works." The soil is of such a nature that the water from the bay would readily find its way to, and even beyond the pipe, covering it with salt water twice in twenty-four hours, leaving it more or less immersed from six to eight hours out of the twenty-four. One would hardly suppose that, with a thickness of but one-eighth of an inch, the pipe would stand the pressure of one hundred and twenty pounds per square inch, but such was the case.

An attempt has been made to charge the change to poor material, but of the 56.6 miles of pipe in the city, this is the first and only thing of the kind found. Again, the pipes taken out were not all of one lot. Of the six, one was made by R. D. Wood & Co., three by the Gloucester Iron Works, and one by the Warren Foundry and Machine Company. The remaining pipe was so badly broken in taking out that it was not identified.

II. Chemical Study of the Corrosion, By Professor Nichols.

Some time ago, I received from my colleague, the President of this Society, a specimen of the corroded pipe referred to by Mr. Borden in the earlier part of this paper. Since then I have received other specimens from Mr. Borden, together with samples of the material in which the pipe lay, and other objects which, it was thought, might throw light upon the cause of the corrosion.

The specimen first received by me was a ring cut from a pipe on which the corrosion was very marked. An inspection of the cut surface showed three tolerably well defined layers: within, a ring of apparently unaltered iron; without, a ring of a brown substance bearing no resemblance to the original iron, being easily cut with a knife and having a greasy feel; between the two, a layer full of black, metallic-looking particles, and easily reduced to a brown powder. I speak of these layers as *tolerably* well defined, because, while they appeared distinct on casual observation, closer inspection showed that they ran into each other and could not be separated, one from the next overlying or underlying layer. In other specimens of the pipe only two layers could be made out, the inner apparently unaltered iron, the outer corresponding in character to the middle layer of the specimen first received. The corrosion had not taken place uniformly, so that the bounding surfaces of the layers were not concentric, but a section through the pipe had the appearance indicated in the figure given by Mr. Borden. In some cases, owing to lack of homogeneousness in the pipe, the corrosion assumed the form of pitting, the pits being filled with a material corresponding to the outer layer of the first specimen described. This outer layer, where the corrosion was complete and where no iron remained in the metallic condition, is perhaps the most interesting. It is light brown, almost yellowish in color, but is full of shining black particles. When heated, it gives off some white fumes and the odor of acrolein, glows, and what remains is of a darker color, almost black. The black particles scattered through the mass are somewhat magnetic before and after heating. When the substance is treated with hydrochloric acid it gives off sulphuretted hydrogen gas; the residue is black, but becomes white on ignition. The results of the analytical determinations are as follows, the second column merely presenting the statement in slightly different form, calculated from the same data:

	Per cent.	
Moisture	6.62	6.62
Oil, etc., before hydrochloric acid	0.96	0.96
Oil, etc., after hydrochloric acid	0.61	0.61
Sulphur	0.41	.....
Sulphur calculated as sulphide of iron	.....	1.12
Phosphorus	2.20	.....
Phosphorus calculated as phosphoric acid (P_2O_5)	.....	5.04
Graphite	14.75	14.75
Non-graphitic carbon	undet.	undet.
Silicon	9.94	.....
Silicon calculated as silica ($Si\,O_2$)	.....	21.30
Iron	32.73	.....
Iron calculated as oxide of iron (Fe_2O_3)*	.....	45.75
Copper	0.22	0.22
Manganese	0.53	....
Manganese calculated as oxide (Mn_3O_4)	.....	0.74
Alumina, chromium, lime, magnesia, chlorine, sulphates	traces.	.....
		97.10

* After deducting the amount contained in the sulphide of iron. Calculated as the oxide $Fe_3\,O_4$ the amount would be 44.22 per cent.

As these figures may meet the eyes of chemists, it is necessary to make a few remarks which will be of more interest to them than to civil engineers. In the first place, no two samples precisely alike could be taken from such a mass, and the results of examinations made by different persons would, no doubt, vary on this account. The moisture was determined by drying the substance at 110° C., until a practically constant weight was obtained. The "oil, etc., before hydrochloric acid" represents what was extracted by ether from the dried substance. This was dried at 100° C., but a perfectly constant weight could not be obtained. When heated, it partly volatilized and partly burned with an odor of acrolein, and left no mineral residue. This oil or grease is partly due to the remains of the coating (coal-tar and linseed oil) with which the pipes were originally covered, and partly, probably, to hydrocarbons in the iron or formed during the corrosion; partly also, in all probability, to oil from the tool used to cut the pipe; but I believe that this is not all. In fact, I found that ether would extract similar oil or grease from the different samples which I had of the slag, or cinder, in which the pipe was bedded, and no doubt this comes from the greasy waste water from the rolling-mill, which, as Mr. Borden says, used to drain into this locality. After treatment with hydrochloric acid, the residue yielded an additional quantity of oil when extracted with ether. This may be due to the presence of an oleate or other fatty salt in the mixture; but oleate of copper or iron were not identified. I propose to study this matter further with another sample, which has not been touched with a tool, and which cannot, therefore, have any oil from this source.

The sulphur is present as sulphide of iron, without much doubt. The phosphorus appears to exist to a slight extent, even in the outside layer, as phosphide of iron—mainly, however, as a (basic) phosphate of iron; and I am inclined to think that this compound, which is readily dissolved out by dilute hydrochloric acid, is what gives the brown color to the mass. The carbon is probably there partly as graphite, and partly in the form of carbide of iron, which is formed when gray cast iron is corroded or dissolved slowly in dilute acids, and to which the formula of FeC_3 has been assigned by Karsten. This would count as graphitic carbon in the analysis. The non-graphitic carbon was not determined, as it would have been impossible to distinguish between that left from the original iron and that due to the protective coating, which is not simply a coating, but is absorbed by the iron.

The silicon is mainly, if not wholly, present in the form of the oxide, silica, but whether it is combined with the oxide of iron forming silicate of iron, or whether the oxide of iron and the silica are simply mixed together mechanically, is a problem which it would be difficult, if not impossible, to solve. The material does not gelatinize with hydrochloric acid, and caustic potash dissolves some of the silica (perhaps about one-half).

The condition in which the iron exists is an unsolved, if not insoluble, problem. Some is there, no doubt, as sulphide, some as phosphide, some as silicide, some as phosphate, perhaps some as silicate. As the material does not precipitate copper from a solution of the sulphate, I do not think there is any metallic iron; as the carbide of iron is magnetic, I do not feel sure of the presence of magnetic oxide, although it is probably there. It was impossible to determine how much iron was in the ferrous condition, on account of the presence of sulphide of iron and of organic reducing substances. Some of the iron may be in the form of a hydroxide like limonite, and the brown color of the mass may be due to this, rather than to a basic phosphate. These conjectures may be taken for what they are worth. If asked to state intelligibly to one not much versed in chemistry, what the corroded material was, I should say that it is mainly oxide of iron and silica, possibly in combination as silicate of iron, together with some 15 per cent. of graphite or plumbago, some 6½ per cent. of moisture, and some 2 per cent. of phosphorus, which is probably there as phosphate of iron, and which corresponds to about 15 per cent. of the phosphate. It having been stated elsewhere that a considerable percentage of alumina exists in the corroded material, I will say that I have been unable to discover more than mere traces.

As to the cause of the very rapid corrosion, various theories have been proposed or have suggested themselves. With reference to the general matter of the corrosion of cast (and wrought) iron in salt (and fresh) water, the classic experiments are those of Mallet, recorded in the British Association Reports for 1838, 1840, and 1843. From his experiments, extending over a period of 387 days, Mallet calculated the amount of corrosion which would take place at the same rate in a century,* and found that, with different varieties of cast iron, the average loss of weight per superficial foot in a century would vary from 11.58 pounds to 16.34 pounds, and the average depth of corrosion from 0.306 inch to 0.431 inch in the same time. This calculation of from three to four-tenths of an inch in a century as the depth of corrosion in cast iron, was found to be somewhat low by the examination of guns taken from the wreck of the *Edgar*, which had been upward of 129 years under water. Here the corrosion was found to be about seven-eighths of an inch on the average. Iron from the Royal George was found, after an immersion of 59 years, to be corroded from one-half to three-fourths of an inch in depth.

Mallet found that in foul sea-water the corrosion took place more rapidly than in clean sea-water, but with nothing like the rapidity of the case before us. His experiments were on specimens of iron wholly and continuously submerged; the alternate exposure to air and sea-water, or to water as salt as that at Fall River,† we should expect to cause an increased corrosion, but this certainly cannot be the sole cause here, because beyond the por-

* Report of the British Association for the Advancement of Science, x. (1840), p. 299.

† See further on, next page.

tion of pipe affected, there is other pipe which has been likewise alternately exposed and submerged without being corroded. It has been thought that the corrosion has been caused by the material in which the pipe was bedded; that some acid or corrosive substance was developed by the decomposition of the slag, or cinder. Some probability attaches to this view, because cases have been known where steam-pipes have been corroded by the escape of steam in the slag-wool in which they were packed. This Prof. Egleston* ascribes to the formation of sulphuric acid from the sulphur in the slag-wool. I must confess that I cannot quite see how an acid should be developed under the existing conditions, and I kept for a long time some of the finely-powdered cinder in contact with water taken from the spot, without being able to discover the development of any acid. I have an experiment in progress which may throw some light upon the matter. In two glass jars I buried small weighed bars of cast iron (portions of the same casting) in powdered cinder (two different samples), and in another jar buried a piece of the same iron in clean sand. These jars were filled with water from Fall River; every morning the water is drawn off and every evening replaced, so that the iron is alternately covered with water and exposed wet to the action of air. After the experiment had gone on for about four weeks, the pieces of iron were removed, cleaned, and weighed. It was found that the iron buried in clean Berkshire sand, and which originally weighed 87.49 grams, had lost 0.15 gram in weight. The pieces buried in the slag weighed the same as at first. I feared the slag might have been too finely powdered, so that the water did not drain away thoroughly, and the experiment is now going on with more coarsely powdered slag. Meanwhile the water has developed no acid reaction.

Another difficulty in the way of considering the slag as the cause of the trouble is that some of the uncorroded pipe lies in similar material. Mr. Borden sent me three samples of filling from the pipe trench: No. 1, from the west end of the decayed pipe, where the pipe was good; No. 2, from the middle ground, where the pipe was bad; No. 3, from the east end, where the pipe was good. The sample No. 1 was a clayey gravel, but Nos. 2 and 3 were essentially the same slag, and there seemed no reason why, if No. 2 was corrosive, No. 3 should not be so likewise. Samples of water were also sent at the same time from the three localities. They proved to be alike in their salinity, as appears from the following statement:

	Percentage of— Combined chlorine.	Total solids.
No. 1	1.43	2.86
2	1.48	2.86
3	1.49	2.82

Samples of the three materials in which the pipe was bedded at these different points were then taken and placed in separate beakers, and each covered with water from its own locality. The water was poured off every evening and poured on again every morning, for about a fortnight. The total solid material contained in the water after this treatment was then determined:

	Percentage of total solids. Originally.	After treatment.
No. 1	2.86	2.96
2	2.86	3.74
3	2.83	3.24

This would also indicate the similarity of the two samples, Nos. 2 and 3.

The cinder in which the pipes are bedded contains a small amount of copper, which might be looked upon as an agent of corrosion. Undoubtedly, if the copper was dissolved out from the slag by the salt water, the iron would be corroded by the solution, and copper would be left on the iron. The amount, however, even in the outside layer, is so trifling that it does not seem as if this could be concerned in the action, and copper occurs in the slag in which the non-corroded pipe lay as well as in that around the corroded pipe.

It is known* that iron structures immersed partly in salt and partly in fresh, or brackish, water are corroded somewhat rapidly, on account of galvanic action between the portions of iron immersed in the liquids of different densities. It suggested itself that the fresher water draining from the rolling mill

* Trans. Am. Soc. Civ. Engr's. XII. (1883), p. 253-261.

* Mallet, Br. Assoc. Rep., X. (1840), p. 227.

might overlie the salter water below and bring about this condition, but samples of water which were taken for me by Mr. Borden at different stages of the tide, proved to be of essentially the same salinity;

	Total solid matter. Per cent.
No. I. Full tide	2.59
No. II. Tide falling when at top of pipe	2.64
No. III. Tide rising	2.61

It has been further suggested that the fault was in the original iron; but, as Mr. Borden remarks, this can hardly be the case, as pipes furnished by three different makers were corroded. I procured a piece of the spigot end of one of the pipes, this end being naturally protected from corrosion, and made a partial analysis, which appears in the table below. I have had no experience with the iron generally used for such water mains, but see no reason to suppose the iron at fault.

The most serious part of the problem before us is not to determine why the pipe has corroded, but why it has corroded here so much more rapidly than on either side of the 72 feet length, most of the conditions seeming to be the same. I may say that I have been unable to visit the locality, and it is within the bounds of possibility, although not very likely, that a personal visit might suggest some things which I have not considered. It is also possible that the cause of the corrosion is one that has acted in the past, but is not acting at present. This we cannot know until the new pipe has been longer in position. With what light I have at present, it seems to me most likely that the corrosion is due, not to any one single cause, but rather to a combination of circumstances which happened to work together to produce the observed result. The pipe is bedded in a very porous material, in which, as the water recedes, the air must circulate freely, but which probably retains enough moisture to keep the pipe wet nearly all the time, even when not actually covered by water. Now, as Mallet states,* "the conditions the most favorable possible for rapid oxydation of iron consist in its exposure to 'wet and dry,' or to air, covered with a film of water constantly renewed."

* Br. Assoc. Rep. (1840), p. 256.

Moreover, from Mr. Borden's statement, it appears that the temperature is such as to favor chemical action. Mallet found that sea-water, at a temperature of 115° Fahr., corroded iron rapidly. It is not likely that the Fall River brackish water reaches that temperature, but still the temperature is probably a factor in the matter. When the locality where the pipe lies was being filled, cinders and hot slag (sometimes red-hot) were dumped within from 12 to 15 feet of the pipe, and an iron pipe now carries the hot drip from the rolls over and within 12 inches of this pipe. For five or six years the pipe was used only for fire purposes, and the water was found to be very warm whenever a hydrant was opened. Now, however, the water runs all the time to supply a drinking fountain. It remains to be seen whether corrosion is less active in the future than in the past.

It is very possible that the air which comes in contact with the moist pipe is (or was) such as to act upon the pipe more rapidly than ordinary air would. It appears that the locality has been, for a long time, the receptacle of drainage water containing much organic matter, and is even now freely used as a urinal. The decomposing organic matter beneath and in the filling, would give rise to carbonic acid and ammonia gases, both of which are corrosive agents.

Whether the air in the interstices of the filling differs from ordinary air, admits, of course, of being ascertained experimentally. At this season of the year I should not expect as much difference as in summer, when the warmer weather would make the decomposition of the organic matter take place more rapidly. However, I suggested to Mr. Borden a somewhat crude method by which samples of the air might be taken, and on three different days he took samples; those marked "E" are from a point about 15 feet east of the west line of the Nail Mill. Those marked "W" are from a point midway between the points A and B on the plan, where the corrosion was greatest. The results of the examination (for which I am indebted to Mrs. Professor Richards) are as follows:

CARBONIC ACID IN 10,000 VOLS. AIR.

		Vols.
April 1, 1885	E.	4.32
	W.	4.99
April 3, 1885	E.	4.94
	W.	4.89
April 4, 1885	E.	4.15
	W.	4.95

Outer air usually contains about 3 vols. in 10,000, and ground air usually more than the samples above. The results are not, therefore, very convincing, but I should like to repeat the experiment in warmer weather.

Of the single suggested causes, I have looked with most suspicion upon the "grease" which comes from the rolls of the iron works, and which is evidently present in the slag and probably in the corroded portion of the pipe. Every one of several samples tried showed grease or oil, but as the pipes had been treated with coal tar and linseed oil, I cannot assert that the oily matter found was not derived from this source. It is well known that the greasy water from surface condensers is very corrosive to boilers, and this is partly due to the fact that the grease is decomposed by steam, and fatty acids are formed. I have not yet satisfied myself as to the existence of oleate (or other fatty salt) of iron in the corroded pipe, and this I should expect to find if the grease were the prime cause. I tested also the various samples of water for grease with negative results; but this of itself would prove little, as the samples were all taken the same day. Moreover, it appears that for several years the pipes were exposed to warm and, presumptively, greasy water much more freely than at the present time.

I must confess that one of the most inexplicable things to me is the insufficient protection afforded by the coal-tar coating. Mallet and other experimenters found that coal-tar laid on hot was one of the most protective coatings, and although there are some tubercules in the interior of this pipe, the coating seems to have been well applied. It is hard to believe that, in this case, an unprotected pipe could have dacayed much faster.

The table on the next page contains the results of the chemical examination of the three layers of the corroded pipe and also of iron from the spigot end of one of the pipes. As the spigot was not from the identical pipe from which the corroded ring was cut, the comparison must not be pressed too closely, but it probably represents nearly enough the original iron. We should expect that as the corrosion proceeded, the iron would be partly oxydized and partly dissolved away as protocarbonate or otherwise, and that the carbon, the silicon, the phosphorus would accumulate to form a larger proportion of the mass. Examination of the figures in the table shows that the graphite, the silicon and the phosphorus do increase in amount from the center outward, and in almost identically the same proportion. It appears, however, that while the iron decreases in the same direction, it decreases much less rapidly.

Some surprise has been expressed at the lightness of the corroded material, and one chemist has suggested the theory that this may be due to the presence of metallic aluminum. There are several objections to this view. In the first place, it is quite unnecessary. A fragment of the corroded part of the pipe (including the "middle" and "outside" layer, as designated above) was found to have an apparent specific gravity of 2.33, bul it was very evident that the lightness was due in part to the fact that the material was very porous, and contained, therefore, a good deal of air. Moreover, as it contained oily matter, it was not readily wet by water. Small lumps heated in water to the boiling point and then cooled down gave a specific gravity of 2.73, and when the material was in the form of a moderately fine powder the specific gravity rose to 2.98.

If now, we take the mean composition of the corroded material (middle and outside layers) to be:

	Per cent.
Moisture	6.11
Silica	17.50
Sulphide of iron	1.04
Phosphoric acid	4.17
Graphite	12.10
Oxide of iron	53.25
Oil, water of hydration, hydrocarbons, etc.	5.83
Total	100.00

and then reckon the phosphate of iron as corresponding in composition and specific gravity with the native mineral dufreynite, and take as the specific gravities of

	Outside layer.		Middle layer.		Inside layer.		Spigot end.	
Moisture	....	6.62	....	5.61	....	und.	und.	....
Silicon	9.94	....	6.41	....	3.31	....	1.77	....
Silicon calculated as silica (SiO_2)	....	21.30	....	13.74	.. ....	7.09	....	3.79
Phosphorus	2.20	....	1.44	......	0.69	....	0.39	....
Phosphorus calculated as phosphoric acid (P_2O_5)	....	5.04	....	3.30	....	1.58	....	0.89
Graphite	....	14.75	....	9.46	....	und.	2.63	....
Iron	32.73	....	43.15	....	72 97	....	93.18	......
Iron calculated as oxide (Fe_2O_3)*	....	45.74	....	60.77	....	.... ..	....	....
Sulphur	0.41	....	0.35	....	0.19	... ...	0.09	.. ...
Sulphur calculated as iron sulphide (FeS)	....	1.12	....	0.96	....	0.52	....	0.25
Copper	....	0.22	....	trace.	trace.	....	trace.	....
Manganese	0.53	....	....	und.	und.	....	0.61	....
Manganese calculated as oxide (Mn_3O_4)	....	0.74	....	....	....	....	....	....
Oil, etc., before hydrochloric acid	....	0.96	.. ...	0.08	trace.	....	....	... ...
Oil, etc., after hydrochloric acid	....	0.61	....	....	....	....	....	....
Non-graphitic carbon	......	und.	....	und.	und.	....	0.77	....
		97.10					99.44	

* After deducting the amount required for the sulphide of iron.

the other ingredients the observed specific gravities of the corresponding native minerals, we reach the following basis on which to calculate a possible specific gravity for our mixture:

	Per cent.		Sp. gr.
Water, oil, etc	11.94	say 12 0	1.0
Silica	17.50	" 17.5	2.5
Sulphide of iron	1.04	" 1.0	4.7
Graphite	12 10	" 12.0	2.2
Phosphate of iron	15.16	" 15.2	3.2
Oxide of iron	42.26	" 42.3	5.2

The specific gravity of such a mixture as this would be 2.63. This claims to be nothing more than a rough approximation, but it shows that knowing the composition and character of the substance, we need not be surprised at the low specific gravity.

Another reason why I cannot accept the aluminum theory is that, from our knowledge of the difficulty with which aluminum is reduced from its compounds and obtained in the metallic state, I cannot conceive how the reduction could take place when the tendency of all the constituents of the original iron is to become oxydized. No one would claim that this oxydation could be effected in the wet way by the reduction of aluminum compounds.

The third reason for rejecting the aluminum theory is that there is only the merest trace of aluminum present in any form.

Since this paper was read another sample of the corroded material has been submitted to partial analysis. This specimen came from near the bell end of the same pipe, the spigot end of which was taken as a sample of the original iron. The surface here showed the asphalt coating still remaining, and only two layers could be distinguished. The inner layer was not analyzed, but did not seem to be wholly unaltered iron; the outer layer was harder than in the specimen described above, although it could be reduced to a fine powder without difficulty. The results of the partial analysis were as follows:

	Corrosion. Bell end.	Original iron. Spigot end.
Moisture	3.87	Undet.
Oil, etc., extracted by ether	0.40	Trace.
Oil, etc., after hydrochloric acid	0.22	0.00
Iron	52.94	93.18
Graphite	7.93	2.63

THE THEORY OF GAS ENGINES.

From "The Engineer."

In the case now pending, Otto *v.* Steel, much importance has been attached to a paper by a French *savant*, M. Beau de Rochas, entitled "Nouvelles Recherches sur les Conditions Pratiques de plus Grande Utilisation de la Chaleur et en General de la Force Motrice." This paper was published in Paris in 1862. We give a translation of it, not only in order to make the course of events clear in the case of Otto *v.* Steel, but because it is really a very valuable contribution to the theory of heat-motor engines:

Combined gas and steam motor.—When we examine what takes place in the combustion chamber of the gas-fired boiler, we are struck with the enormous volume which gases raised to a high temperature attain. If the combustion, on the other hand, takes place at constant volume, the dilation will be replaced by an equally considerable accession of elastic force, and the return to the original pressure by means of expansion will give precisely the same volume at the same temperature as if the heating had originally taken place under constant pressure. It is directly evident from this that in the mere fact of combustion there ma be a production of power of an order of considerable greatness, and completely independent of that which would afterwards result from the formation of steam by the cooling of the burnt gases, from which we conclude that the complete utilization of the phenomena of combustion requires that we should at the same time profit by the elastic force which gases can directly acquire from combustion at constant volume, and the elastic force which they can subsequently communicate to steam by giving up to it their dilating heat, a heat which is identically the same as if they had been heated without producing an excess of elastic force over the surrounding pressures. This complete utilization would have been manifestly impracticable with the use of solid combustibles alone. It becomes infallible on their previous conversion into gases, which are themselves combustible. And such is the immense final result of the invention of gas furnaces, the priority in which belongs to Messrs. Thomas & Laurens, but in respect of which it is only fair to afford considerable recognition to the scientific labors of Messrs. Helman, in France, and Faber Dufaur, in Germany. We must henceforth, then, consider as essentially incomplete—and so consider from our knowledge of the cause—all gas engines alone and steam engines alone, and it is easy to demonstrate that the one is necessarily the normal complement of the other. The action of gases as vehicles of motive force assumes the previous starting of the motor apparatus, for precisely because gases exist already formed and cannot do work without expansion, they are incapable of setting themselves to work, and can only act as active agents into a system already in motion. It is for this reason there have never been, and there never will be, gas engines, whatever their principle, which can be applied to cases in which the starting requires more or less powerful or rapid effort without the simultaneous concurrence of some external force. Gas engines, pure and simple, are therefore, essentially engines of small powers. Steam-engines, on the contrary, are capable of the most powerful direct action, but at the price of an excessive expenditure of heat. That is, in effect, how M. Regnault expresses himself on this point—*Comptes Rendus*, April 18th, 1853: "In air-motors—allowance being made for exterior losses and for mechanical obstacles which may present themselves in practice—all the heat expended is utilized for working power, while in the best steam-engine the heat utilized in mechanical labor is not the twentieth part of the heat expended, and it is even much less in most casas." This normal inferiority of return is a certain sign that steam alone cannot be a truly economical agent for the transmission of work, but the very mechanism of its formation makes it the indispensable starting agent. Such, then, is the proper use of steam, to be, if not the preponderating expansive power, at least the finger always ready to press the trigger. This proposition may appear in contradiction to certain facts which would tend to establish that it is difficult to obtain from gases a great power of expansion. The permanent gases appear, in fact, perhaps even more sensible than vapors to the various causes of loss of heat. But we must distinguish between normal losses and accidental losses, notably by dispersion. Permanent gases ought to be considered as vapors infinitely below their point of saturation, and it is impossible that they can restore in any case one particle of their specific heat, and it follows from this, they ought, in working, to cool at a much greater rate than vapors. But it is of little importance whether the curve of pressure falls more or less rapidly on expansion, if the useful effect is, in the end, more considable. As for the accidental losses, if, in combining the gas-engine with the steam-engine, we arrange things in such a way that these losses are turned more especially to the profit of steam-raising itself, we have realized the maximum practical effect, for even if gases are really difficult to handle, it is chiefly by reason of their great dispersive power, and if the losses accruing under this head, already supposed as reduced to their best possible use in a corresponding production of steam, we have all the useful effect of the steam, as hitherto, plus that which we can obtain from the elastic force of the gas itself. In conclusion, it is necessary to observe that among the necessary and rational conditions of transmission of force the first appears to be the very existence of a mass of superabundant heat, and the limit of practical utilization of this is manifestly arrived at when the quantity of heat necessary for the formation and maintenance of this mass is brought to its lowest point by disposing in their rational order the only physical agents which we can generally use, namely, fuel, air and water. This is the leading idea of the mixed gas and steam-motor, a natural consequence, also, of the application of gas furnaces to the heating of steam boilers. The simultaneous utilization of the expansive force of gas and steam will generally require the employment of two sets of cylinders, viz., those in which combustion is effected, and steam cylinders. The most simple arrangement will consist in making the in-draught of gas from the cupola, and of the fresh air necessary for combustion by the suction of the gas cylinder itself, and in forcing out, after their expansion the burnt gases in the steam boiler, the exhaust of the steam cylinder, will then serve most readily to diminish the cushioning of the gas cylinder by facilitating the expulsion of the burnt and cooled air out of the engine, at least unless we can find a more useful employment of the steam in condensing it. There being nothing requiring modification in the arrangement of steam cylinders, the practical use of which appears to have followed close upon their being perfected in each particular case, we will only occupy ourselves here with the designing of gas cylinders, the practice in which is much less advanced. We shall distinguish two general cases according as the gas to be burnt is taken at atmospheric pressure or is previously compressed.

Arrangement without previous compression.—Combustible gas and fresh air are drawn in during a portion only of the stroke of the pistons of the gas cylinders. These cylinders thus perform the function of suction bellows by drawing in air for the supply of the cupola. Taps and valves regulate the access and proportions of the two descriptions of gas. The mixture is effected at low temperature, in conduits arranged for that purposes, and ignition is produced by known processes. The volumes of the gas and steam cylinders are arranged in accordance with the expenditure of the two fluids. Nevertheless, the steam cylinders ought to be of themselves powerful enough to start the whole machine. It could then be arranged, according to circumstances, that the steam-throttle valve might be entirely opened for the purpose of starting, and normally more or less closed during working. The high temperature produced in the gas cylinder by direct combustion would be a cause of speedy destruction of the machine, if the walls were not maintained at a very low relative temperature. This low temperature would be an energetic cause of cooling in the gases, if it could not be met by other arrangements. But there will always be only a very slight drawback from direct utilization, if the heat thus dissipated gives return in producing steam. The gas cylinders, as well as their frames, will therefore be surrounded by water, and placed, by means of their exterior surfaces, in communication with the boiler in such a way as to ensure the circulation of the water and the creation of steam. The elevation of temperature, even if very great, would otherwise cause no sensible inconvenience with the walls maintained at a constant temperature. It must be understood, in fact, that the metal walls, even though we suppose them to be very thick, can always transmit the total heat furnished to them without their temperature at the point of contact with the hot air being ever able to rise to an appreciable extent above that of the boiler. The coating of air in immediate contact with the wall will always then be in instantaneous equilibrium of temperature with it. The propagation of the cooling through the gaseous mass will otherwise always proceed in accordance with the laws of dispersion—that is to say, in proportion to time and to distance. An analogous action takes place in the piston faces, in the castings in front, and in the piston rod, for these surfaces incessantly exchange radiated heat, and cannot, therefore, differ sensibly in temperature. The temperature of the gaseous mass, for a given position of the piston, will be highest then in those parts furthest from the cool walls. It will at first only vary slowly, and will only commence to fall really suddenly at a small distance from the same walls. The conditions of procedure, then, will not be sensibly different in gas and steam cylinders; there will be nothing to change essentially in the pistons, stuffing-boxes, &c., the lubrication of which can be effected by ordinary processes. The work produced being in proportion to the pressure produced by the combustion, it is desirable to preserve the highest possible value of this factor, for we can always regulate the strength of the machine accordingly. Besides, it is the special advantage of gas-engines that they admit, without danger, of pressures in the cylinders in which combustion takes place which would be unattainable in a steam boiler. Now, we attach in practice a greater and greater value to increase of pressure, and with reason, for in pressure alone lies not only the cause of motion, but, above all things, the utilization of force. Pressure being in inverse ratio to the temperature before ignition, it is important that the gas from the cupola should be, as far as possible, cooled before its entry into the cylinder. With this object the boiler will be furnished with two systems of tubes, one on the side of the cupola, the other on the side of the exhaust, in such a way as to form two interior compartments, separated, at least, by a partition impermeable to air. The fireproof jacket of the interior cylinder will be done away with as useless in the case in question. Consequently, the combustible gas will be drawn from the first compartment, after having traversed the tubes in it, and being brought to the temperature of steam, or thereabouts. The burnt gases will be driven into the second compartment, and discharged by the chimney after being equally cooled. The condition of things of which we are treating requires that the steam should be of the lowest pressure possible. It must not descend, however, below the point at which the temperature will be insufficient to cause the precipitation of the calcareous salts in the purifying apparatus, which is in this case absolutely indispensable. The pressure in the boiler, therefore, should never exceed six or seven atmospheres.*

The pressure is, moreover, proportional to the temperature of combustion. This temperature will be highest when we only admit the amount of fresh air absolutely necessary for combustion. It is to these particular conditions of air supply that the maximum effect of the engine will evidently correspond. The effect will diminish in proportion as, in accordance with the work required, we admit a greater or less excess of air, or, what comes to the same thing, we more or less close the regulator of the cupola. But even in the case in which the duty of the engine is smallest, it is still desirable to work with the maximum useful effect. Now, for a combustion tempera-

* Here there is, however, a question of maximum for the total work of the gases and of the steam, which we can only indicate in passing.

ture corresponding to a given proportion of combustible gas, and consequently to a known pressure after combustion, there is a certain length of suction — we should say "inlet" in case of a steam cylinder—for which the work developed in the cylinder is a maximum. The variation in amount of suction answering in each case to the maximum of work, being confined within narrow limits, the use of a slide will perfectly suffice to obtain the greatest variation in the yield of combustible gas. The arrangement, therefore, of the gas cylinders in the case in question can be made in the simplest manner with a common slide-valve, modifying, it is always understood, the forward and backward movements of it, to meet this particular requirement.

Arrangement with previous compression.—The arrangement before described appears certainly the simplest that could exist. It will perhaps be the only one applicable to locomotives. Then the increase of utilized power resulting from it will certainly be clear gain and without any doubt out of proportion to the cost of setting up. But the true conditions of the best employment of the elastic force of gases, at least its most important conditions, are not there observed, and simplicity is, perhaps, only acquired at the expense of utility. These conditions, in fact, are four in number — (1) the greatest possible cylinder space with the least possible exterior surface; (2) the greatest possible quickness of action; (3) the greatest possible expansion, and (4) the greatest possible pressure at the commencement of the expansion. The dispersive power of gases, so favorable to the use of boiler tubes, is evidently, on the contrary, an obstacle to the utilization of elastic force developed in the gaseous mass. Now, we have seen that in the case of boiler tubes the efficiency —that is to say, the heat transmitted— was proportional to the diameter of the tubes. The loss would, therefore, be in inverse ratio to the diameter in the case of cylinders. But that is only applicable to cylinders of very small diameter, and the loss decreases in reality in a more rapid proportion than the diameter increases. Therefore, an arrangement which, for a given consumption of gas, will give cylinders of the greatest diameter will be that with which the greatest direct utilization of heat will correspond in this respect. We equally conclude from this that, as far as possible, we must only employ one gas cylinder in each separate machine. But dispersion depends also upon time. Cooling, then, will be as much greater, other things being equal, as the working pace is slower. Now, a more rapid working pace seems to imply as a consequence cylinders of a smaller volume; but this contradiction disappears when one reflects that the length of stroke is not necessarily related in an invariable manner to the cylinder volume for a given expenditure. In like manner as for the elastic force of steam, the utilization of the elastic force of gases requires that the expansion should be the most prolonged possible. In the arrangement above described there is a maximum of expansion for each particular case. Thus the effect is necessarily limited. The advantage, therefore, rests with an arrangement which will permit of giving back to the machine that which we may call the free play of the expansion, that is to say, the power of expanding so far as we may think it convenient within the limits only imposed by the nature of things. Finally, the utilization of the elastic force of gases still depends on one element which is entirely their own, but which is at bottom intimately connected with the utility of prolonged expansion. This element is compression, which should be the greatest possible for the greatest effect. It can be easily seen that we are dealing here with heated expansion obtained after cold compression, which is a way of prolonging the expansion in some sort inverse to that which consists in causing a vacuum, a way to which steam could not adapt itself, it being always understood that all compression causes inevitably an equivalent condensation in such a way that, even supposing steam to be combustible, instantaneous heating would be rendered impossible by reason of it. We can, therefore, theoretically get as indefinite a utilization of the elastic force of gases by compressing them indefinitely before heating, as we can get an indefinite utilization of the elastic force of steam by indefinitely prolonging expansion. But practically we soon attain an impassable limit. It is that at which the raising of temperature due to previous compression brings about spontaneous ignition. In fact, in their continuing compression we shall only recover from the expansion up to this same point the work furnished by compression, less the loss occasioned by all useless action. There, then, is the limit imposed by the nature of things, and the final advantage in respect of utilization will rest with an arrangement which will permit of its attainment. The question being thus propounded, the sole arrangement really practicable consists evidently in forthwith employing but one cylinder, so that it is the largest possible, and further in reducing the resisting movements of the gases to their absolute minimum. Then, and for the same side of the cylinder, we are naturally led to execute the following operations, in a period of four consecutive strokes: (1) Suction during an entire stroke of the piston; (2) compression during the following stroke; (3) ignition at the dead point and expansion during the third stroke; (4) forcing out of the burnt gases from the cylinder on the fourth and last return stroke. The same operations being reproduced on the other side of the cylinder in a similar number of strokes of the piston, there results a particular sort of single-acting machine, we might say of *half-power*, but which evidently satisfies the condition of largest possible cylinder, and at the same time that condition, which is still more important, of previous compression. We see at the same time that the velocity of the piston is the greatest possible in relation to the diameter, since we do in a single stroke the work for which we should otherwise take two, and we evidently cannot do more. The temperature of the gas coming from the cupola is appreciably constant. That of the external air relatively varies only between narrow limits. Then the initial temperature of the mixture at the moment of the suction into the cylinder will also be appreciably constant. It will therefore be possible to determine the limit of compression at which ignition would become inevitable, and to arrange the machine accordingly. We shall thus constantly have the absolute maximum effect for each proportion of combustible material. We shall at the same time be freed from the intervention of electricity, for, the starting being effected by the action of the steam, the gases need never be introduced until the speed shall have become sufficient for ignition to be produced with certainty. In all cases compression will favor instantaneous ignition by helping complete mixture, and in raising the temperature. In fine, and with an initial temperature corresponding to a pressure of five to six atmospheres in the boiler, ignition will be spontaneously produced with a degree of compression reaching to about a fourth of the original volume—at least, if we neglect the effect of dispersion. Then the pressure after ignition would attain barely thirty atmospheres, and as we are dealing here with the case in which combustion is effected without excess of air, the pressure would necessarily be lower in all other cases. It is, therefore, probable that in many cases we can really attain the absolute limit of utilization. To sum up, while manifestly lending itself, in the completest possible manner, to the utilization of elastic force developed in the gaseous mass by combustion under constant volume, the arrangement now in question is not less simple than the preceding one—at least, unless we consider as a complication the necessity, or rather the convenience, of employing in some cases distribution by clack valves. This distribution is generally the most advantageous, and there is nothing to prove that it is not generally applicable even to locomotives, and, above all, to the case in question.

The Diamond Drill in New South Wales.—The diamond drill is doing good work in discovering or proving coal in various parts of the colony, the most important recently discovered being a seam of good coal, some 12 feet thick, in the parish of Heathcote, 28 miles from Sydney on the Illawarra Railway. The drill pierced this seam at 847 feet below the surface. Hitherto all attempts to find coal near Sydney have been unsuccessful. When the Illawarra Railway reaches Heathcote it will be possible to send coal from the mine to Sydney by rail at a very moderate cost, and vessels will be able to coal at Port Jackson.

WATER SUPPLY.

By WILLIAM POLE, F. R. S., M. Inst. C. E.

A Lecture delivered before the Institution of Civil Engineers.

Mr. President and Gentlemen,—It was with considerable diffidence that I undertook to deliver this lecture on Water Supply. You all know that we have in our Institution some veterans who have acquired world-wide fame in this department of engineering; and it was not till I had been assured that there was no hope of getting any of them to undertake it that I would listen to the application. I am not, as they are, renowned for the construction of water-works; but it happens that, during almost the whole of a long professional life, I have been occupied, more or less, in the study and discussion of matters connected with water supply, and I suppose it is on this account that the Council have done me the honor to apply to me.

And, in reality, my task is not a very difficult one; for, thanks to the great ability and long experience of the masters of the craft, the modes of effecting water supply have been pretty well settled. My chief duty is to give a very general view, without much detail, of the principles and practice that appear to have been established in this matter, and if I can succeed in doing this clearly, it is all I can desire.

The prospectus of these lectures gives the general title of "The Theory and Practice of Hydromechanics." I have little to say about theory here, as the problems affecting water-supply works are chiefly the same as for mechanical and structural engineering generally.

In regard to the theory of hydrodynamics, I may refer you to an able article lately published in the "Encyclopædia Britannica," by a Member of our body, who has made this subject specially his own, Professor Unwin; and as you will shortly have the pleasure of hearing a lecture by this gentleman, he will probably give you some remarks on the point. I will only say a word as to the special problem of the flow of water along channels of various kinds.

There are certain simple and well-known formulæ and tables which, by long experience, have been found fairly suitable for ordinary purposes. But later researches have shown that in many points they require amendment when a greater approach to accuracy is desired. These researches were made some years ago, by two French engineers, MM. D'Arcy and Bazin; and the points they chiefly laid stress on were two:

In the first place, it had been usually assumed that the retarding force of the friction was independent of the nature of the surface of the channel. This was found to be an error, different materials requiring different coefficients.

And then, secondly, it was discovered that the relations between the velocities of the current at different parts of the section had not been correctly determined, and had values varying greatly under different circumstances.

I am not going further into these matters; they can easily be referred to if required. And having said this, I will proceed to the more practical views of water supply.

In the admirable Introductory Lecture we have heard explained the general phenomena by which the great element, water, is delivered on the earth for our use. We have now to enter on what is more strictly the province of the engineer in regard to water. We have to show how the stores of this invaluable substance can be, and are, made available for the use and convenience of man. This is done in many ways. The engineer has to provide and distribute supplies of water for the food and the various necessities of congregated populations. He has to make available the ample natural stores of mechanical water-power. He has to direct and control the natural flow of surface waters, by operations of drainage and river regulation. He has to take advantage of the fluid mobility of water, by using it to form highways of minimum traction in inland navigation. He has, moreover, to design floating vessels to ravel upon water. And he has to provide for the safe and convenient communication of such vessels with the land, by harbors, docks, and piers.

All these works in the aggregate, with their almost infinite expanse of detail, constitute the great branch of our profession called hydraulic engineering; and this will form the subject of the remaining lectures of the present course.

But before I enter on my humble share of the work, I should like to mention an interesting historical fact, which I think is not generally known, namely, that it is especially to hydraulics that civil engineers are indebted for their origin and existence as a separate and independent profession.

The term "engineer" was originally applied to military men. Building-works in civil life were constructed by the architect, who in all ages has been a well-recognized practitioner.

A century or two ago, however, a new and peculiar demand arose in this wise. The great rivers in the north of Italy had relapsed, by neglect, into a very bad state, giving rise to disastrous inundations. The nation became alarmed, and the most learned scientific men of the day were consulted as to what should be done. This gave rise to a series of valuable theoretical and practical studies, which are of great historical interest, as having formed the basis of hydraulic engineering. The knowledge spread rapidly throughout Europe, and gave a great impulse to hydraulic operations generally.

But there was now a want of competent men to execute them. The architects found these new studies foreign to their own proper business; and so a new class of practitioners sprang up for hydraulic works; with which soon became associated other works of analogous character. Such a class required a new name, and this was easily found. It was noticed that the kind of work undertaken by these new practitioners corresponded to that allotted to the engineers of the military service; and the new profession adopted the same title, prefixing, however, the epithet "civil," to indicate that they were civilians, and so to distinguish them from their military brethren.

Hence the origin of the present term, "civil engineer," an origin which, as I have said, was due entirely to the cultivation of hydraulic science, and its application to works of hydraulic construction.

The expression, "water supply," in its general sense, may have a wide interpretation. It may refer to supplies of many kinds, and for many different objects. But there is one kind of water supply which stands pre-eminent and before all others, namely, the supply to the inhabitants of towns. It was this that was probably in the minds of your Council when they drew the title of this lecture, and I shall not err in directing attention specially to it.

I need hardly enlarge on the value of water. I suppose it is the most important natural substance known, and the most indispensable for maintaining the present order of things in organic life. The old Greek sentiment, Ἄριστον μεν υδορ, was a natural prompting; some ancient philosophers supposed water to be the primordial element of which every living being was composed; and this is so far true, that water forms a very large part of the bodies of plants and animals, and constitutes, either simply or in combination, the greater portion of their food. The need of water for the life, health, comfort, and occupations of mankind, is patent to everybody; and hence the provisions for a due supply of it, of proper quality, in ample quantity, and in a convenient manner, become an absolute necessity of civilization.

History.

In the earliest times people helped themselves from the nearest brooks or streams. But this hand-to-mouth process was only available in certain places; and as it was observed by unmistakable signs that the superficial strata of the earth often contained water, the idea occurred to some ingenious person that this water might be got at by simply making a hole in the ground, or, in other words, "sinking a well." Wells are mentioned as sources of water supply in the oldest records we have, and the art of sinking and working them had arrived, in early ages, at great perfection.

But still even wells could not be got everywhere, and as populations increased, some further extension of water supply became necessary. The simplest plan of meeting this want was to carry the water in suitable vessels from the stream or the well where it was found to the places where it was required. And, primitive as this plan appears, it has lasted into quite modern days. I recollect, when I lived as a boy in a large English town, seeing water carried about for sale, in cans with a yoke, as milk is often carried here; and even a few years ago, being in a fashionable watering-place for my health, I was advised by the local doctor not to use the town supply, but to drink the water of a neighboring spring, brought round in a barrel on wheels every day.

But the more appropriate device soon presented itself of conveying water from distant sources by means of conduits, slightly inclined, so as to allow the liquid to flow along them by its own gravity. This was, indeed, only a direct artificial imitation of natural streams. It is very old, and is mentioned by Homer. It began in leading streams along the surface of the ground; but it ultimately developed into the supply of towns by the ancient aqueducts with which you are all acquainted, and which culminated in the magnificent water supply of the Eternal City.

These aqueduct-conduits usually terminated in public fountains within the town, from which the inhabitants could, without much trouble or inconvenience, get the water carried to their dwellings. Everybody who has been in Rome has admired the fountains there, and they are very common in continental cities generally.

The next great step in municipal water supply, namely, that of delivering the water into the houses of the inhabitants, is of comparatively late introduction. It depended on a considerable degree of mechanical advancement; for to carry out such a system it was necessary to convey the water in pipes under pressure. There is no doubt that pipes of earthenware, of wood, and of lead, were used by the Romans to some extent, but they were very imperfect, and nothing existed in the shape of such fitting as would be necessary for house supplies. The first application of the house supply that I can hear of was in London, brought about by the historically celebrated waterworks of Peter Morice, the Dutchman, established at London Bridge, in 1582. Here water-wheels were erected which pumped the water from the Thames, and forced it along pipes laid through the streets, to the places where it was required; and it is clearly stated by the well-known antiquarian authority, Stowe, that "the Thames water was conveyed into men's houses by pipes of lead."

When this convenient system was once established, it was easily seen that the more ancient conduit supplies might also be adapted to it, by bringing the water into a reservoir at a high level, the hydrostatic pressure from which would answer the same purpose as the pumping pressure in the former case. This was done in the New River supply, brought into London in 1613.

Here, therefore, we have the two types of pumping and gravitation supplies on which all succeeding works have been modeled, with only improvements in detail.

The original London street pipes were, if small, of lead, and, if large, of wood. About the middle of the eighteenth century cast-iron pipes were used, but their high price prevented their general adoption for a long time; it was not till about 1810 that this material may be said to have come into common use, and it was only after that date that the water supply of towns could take any great development. This development did follow, in the attainment of a higher pressure, and generally a better and more ample supply, and the improvements have been continually progressing to the present day.

Before considering the various modes of effecting the water supply in towns, it is necessary to say a few words on two points of a general nature which bear alike on all modes of supply. These are the quality of the water, and the quantity of it which is likely to be required.

Quality of Water.

The quality of water to be supplied to a town is a matter of great importance. This is a subject properly belonging to chemistry, and the aid and advice of a professional chemist must always be called in upon it. But still, any engineer concerned in a water scheme would be at a manifest disadvantage, if he did not know enough of the matter himself, to enable him at least to form a preliminary judgment on the sources of supply.

Rain-water, as distilled in the clouds,

may be considered as practically pure; but it seldom happens that it can be collected and stored without having undergone some contamination. However directly we may attempt to catch it, it will be liable to take up some foreign ingredient from the collecting surfaces, and if it percolates through the earth to springs and wells, it will gather a still greater amount of foreign matters.

The impurities taken up may be classed under three heads:

I. Substances mechanically suspended in the water.

II. Mineral substances chemically dissolved in the water.

III. Dissolved organic impurities.

This classification is not strictly definite in a chemical sense, but it is convenient as regards the importance of the impurities in the view of the engineer.

I. *Suspended impurities* are chiefly found in the water of rivers and streams. They come from the water washing over earth, clay, mud, sand, refuse, etc, the finer particles of which it carries away, and holds in mechanical suspension. "Dirty water," "turbid water," "muddy water," are only other names for water containing matter in suspension. This kind of impurity is of the least importance to the engineer, seeing that it admits of thorough removal by easy means. Two operations are used for this purpose, viz., subsidence and filtration.

Subsidence is simply allowing the water to rest, when the grosser and heavier particles, which are only kept in suspension by motion, will fall down. Everybody who has seen the Lake of Geneva will remember that the Rhone, which flows in at the head in a muddy stream, issues out at Geneva as clear as crystal. The lake is simply a vast subsiding reservoir.

It is impossible to make ordinary subsiding reservoirs as effective as Lac Leman, but they will do a great deal of good, and down to the year 1829, they were the only means used for purifying water supplies. The defect of them is, that some of the suspended matters are so light that they will not subside without much more time than can be allowed, and to remove these matters, an additional process is used, namely, filtration.

This is exactly analogous to ordinary filtration, the water being passed, at a slow rate, through a porous material, of such fine texture as to stop the suspended particles, and allow only the clear fluid to pass through.

This contrivance, as applied to water supplies on a large scale, originated in London in 1828. A Royal Commission had reported that the Thames water supplied to the metropolis was very dirty and objectionable, and the late Mr. James Simpson, the engineer of the Chelsea water-works, determined to try what could be done to improve it. It was known that fine sand was a good and efficient material for effecting filtration; but the difficulty was how to apply it on a large scale, so as to render the cleansing of the filter reasonably practicable. It occurred to him that if the water was allowed to pass downwards through a bed of fine sand, held up by underlying layers of coarse gravel and stones, the dirt would not penetrate into the mass, but would be stopped at its upper surface, and in this way the whole cleaning operation necessary would be to scrape this surface off to a slight thickness, and, when it had become too much diminished, to put fresh sand on. The first water-works filter on this plan, of one acre area, was set to work by Mr. Simpson, at the Chelsea water-works, in 1829. It was found to work well, and has furnished a model, with scarcely any material change, for all subsequent time.

The filtering action has been above described as purely mechanical, *i. e.*, as arresting the suspended particles, and nothing further. But careful observations on the process have lately led to a belief that it exercises some chemical purifying action on the dissolved organic matter. The nature of this action is at present obscure. It is supposed, however, that some kind of oxydizing process may be encouraged in the passage through the pores of the material; and it is certain that, by the expedient of intermitting the filtration, so as to allow of the aeration of the material, this effect may be rendered much more active.

It is important that in ordinary sand filtration the process should not be hurried. Slowness promotes good purification, and the rate of passage through can be regulated by the head of water over the sand. The result of experience with London water is, that the rate of passage should not exceed 2½ gallons per hour through each square foot of area. At this rate each million gallons a day will require 16,700 square feet of filter at work, and allowance must be made for one filter bed being always out of use for cleaning.

In some peculiar cases, special materials have been used instead of sand. It has been found, for example, that certain compounds of iron have a remarkable effect in destroying organic matter. The town of Wakefield has been for a long time supplied from the River Calder, the water being so impure, that a letter written with it was published by the Rivers Pollution Commissioners. Yet the unwholesomeness of this was checked by filtration through a magnetic carbide of iron. Another case has been lately described to this institution by Mr. Wm. Anderson, where the water supplied to Antwerp was purified by Bischoff's spongy iron in the same way.

The two operations, subsidence and filtration, are usually combined, the advantage being that the previous extraction of the grosser particles gives the filters less to do, and allows them to work longer without cleaning.

II. But, though the water may be clear and bright, it may contain a different class of impurities, namely, *mineral substances chemically dissolved* therein, that cannot be removed by filtration.

Such dissolved matters exist in water sometimes in great extent and variety, forming what are called mineral or medicinal waters. These, however, are altogether exceptional; there is practically only one substance which affects water likely to be used for town supplies, and that is lime. Calcareous rocks occupy, it is said, four-fifths of the earth's surface, and as their material is, to a certain extent, soluble, the waters percolating through them take lime up in their passage. Hence, lime is found largely in wells and springs, and as superficial streams are almost always fed partially by springs, rivers contain lime also. The river Thames, for example, after perfect filtration, contains about 15 to 20 grains of solid matter in solution, which is almost entirely composed of salts of lime.

These salts communicate to the water the peculiar quality called *hardness;* soft water makes a lather freely, but hard water has a disposition to decompose or curdle soap, by the combination of the lime with the alkali.

There has been a great deal of discussion as to the comparative merits of hard and soft water for town supplies, and the subject was thoroughly investigated by the Royal Commission on Water Supply in 1869, to which I had the honor of being secretary. I may give you, in a few words, the result of their inquiries.

There are two uses of water to be considered—for drinking, and for washing and manufacturing purposes.

For dinking, there have been contradictory opinions as to the effect of hard water on health. Some say it causes calculous diseases; others say it promotes the formation of a healthy bony frame. But, when the evidence is examined, there is no reason whatever to suppose that a moderate hardness, like that in London, is in the least degree prejudicial.

And it has advantages in many respects; the water is pleasant to the taste, and by its less solvent power it is free from action on lead, which is often dangerous with very soft water. It is also less absorbent of gases and organic impurities, and it keeps better.

For washing and manufacturing purposes, however, the advantages of soft water are undeniable, and in towns where the uses of water for these purposes largely predominate, every effort should be made to procure a soft-water supply. Glasgow and Manchester are striking examples of how this may be done; and it is fortunate that the great manufacturing districts of England are so situated as to render soft-water supplies easily available. But from the great prevalence of the limestone formations, this is not possible everywhere; and where, as in London, a supply of moderate hardness is close at hand, it is a comfort to know that it may be used without material disadvantage.

I say of *moderate* hardness, but it often happens that the hardness is not moderate. The water from chalk wells, for example, sometimes contains 30 to 50 grains of lime-salts per gallon, when the use of the water may become very troublesome.

But nature has provided a remedy for

this, inasmuch as such water may be easily softened. The salts of lime are generally carbonates and sulphates, the former predominating. Now, carbonate of lime is very slightly soluble in pure water, only to the extent of about two grains in a gallon. The reason why natural water often contains so much more is the presence of free carbonic acid, which acts as a solvent, and enables the water to take up the extra quantity.

If, therefore, we can, by any means, drive away this carbonic acid, the superfluous carbonate of lime will be precipitated, and the water will be softened.

This may be effected in several ways:

1. By exposure of the water to the air, when the carbonic acid flies off spontaneously. Open channels conveying very hard water are often found to collect deposit from this cause, a striking example of which may be seen in the celebrated ancient aqueduct of the Pont du Gard, near Nismes. Stalactites and stalagmites in limestone caverns are formed in the same way, as are also the deposits in what are called petrifying springs.

2. By boiling. Every washerwoman knows that hard water may generally be softened by boiling, which drives off the carbonic acid rapidly. The deposit in boilers, so well known and so troublesome, is a result of this action. Many calcareous waters contain other salts of lime besides the carbonate, and these boiling will not remove. Hence it is customary to speak of the *temporary* as contrasted with the *permanent* hardness, the latter being the hardness which remains after boiling.

3. Another way of treating hard water is by adding simple lime in its caustic state. This seizes the free carbonic acid in the water, forming a carbonate, when both this and the carbonate already in the water are precipitated, and may be removed. It is curious that the hardness of water, which is due to lime, should be diminished by adding more lime; but the explanation is very clear.

This softening process, by means of lime, is due to the late Dr. Clark, of Aberdeen, who urged its adoption very warmly. In 1850 I assisted, under his direction, at some trials at the Chelsea water-works, to judge of its applicability to London water. We found it could easily be done, but it was expensive, and the general opinion was that the advantage was not worth the cost.

It has, however, been successfully applied elsewhere. In the same year Mr. Homersham adapted it to some large print works, and he afterwards put it in practice at Plumstead, at Caterham, and elsewhere. One of the latest and most successful applications has been made by Mr. Bateman at the Colne Valley Works, near Watford. The water, which comes from chalk wells, has naturally about 18 to 20 degrees of hardness, and is softened down to 5 degrees.

Some modifications of this softening process have lately been contrived. The most important one has been devised by Mr. Porter, with the view of doing away with the deposition in reservoirs, which is not only expensive, but takes a long time. He agitates the mixture, so as to produce quickly and thoroughly the necessary chemical change, and then passes it through a filtering press, which retains the precipitate, and allows the clear water to be forced through. It is also worthy of mention that Mr. Hallett, mayor of Brighton, has shown that by very simple and inexpensive apparatus a softening process may be adopted in private houses, wherever thought desirable.

III. The third kind of impurity is *organic impurity*, and this requires very careful consideration. But it will be convenient to postpone the remarks upon it till we come to speak of river supplies, in which it chiefly prevails.

Quantity of Water Required.

We now come to the other preliminary point. Before an engineer can take proper steps for the supply of a town he must form an estimate of the quantity of water he will require.

The water consumption in a town varies according to the occupations of its inhabitants, and the nature of the industries carried on, as well as, in some degree, on the habits of the people in regard to the use of water.

The quantity actually required for domestic consumption, including a fair allowance for general household purposes, for water-closets, and for ordinary ablutions, is probably not more than about 10 gallons per head per diem. But in addition to domestic consumption, supplies have to be provided for gardens and stables, manufacturing and trade purposes of many kinds, baths and wash-houses, public fountains, watering streets, flushing sewers, and extinguishing fires. The quantity for these purposes will vary considerably, say from 5 to 10 or more gallons per head per diem.

As a general rule, however, if the town contains nothing likely to make the consumption abnormal, it is usual to estimate that about 25 gallons per head per diem will be, or at least ought to be, a sufficient supply for all purposes.

I say ought to be, because there enters into this question a very important element, namely, waste. I shall have to speak about this hereafter, but I may say here that as a general principle the supply of more water in a town than is reasonably required for the health, comfort, and occupations of its inhabitants, and for the general sanitary public requirements, is an evil, and ought to be discouraged and repressed. Water is a very expensive thing to provide, and its excessive use not only wastes money, but does positive mischief by increasing the difficulty of carrying it away. An engineer, therefore, in designing water-works has a right to anticipate that reasonable care will be exercised to keep down the consumption to what is actually necessary.

At the same time, he must not stint his preparations; for in designing works for water supply, provision ought always to be made for increase of population. There are few towns of importance that do not extend their limits from year to year, and the cases where difficulty has occurred, from insufficient water provision being made for these extensions, have been frequent and troublesome.

It is important to remember that the consumption is not uniform. It has a considerable fluctuation at different hours of the day, and also at different parts of the year.

The daily fluctuation is caused by the variations in the demand for water at different hours, which is very considerable. The following table is the result of observations carefully taken under the direction of Mr. Ayris, who has kindly allowed me to make use of them for this lecture.

It is not easy to account for all the irregularities, but the general result is that, as might be expected, the consumption in the day time much exceeds that during the night, amounting at one time to above twice the average rate. This is about 10 A. M., when the domestic use of water may be supposed to be the most active.

PROPORTIONATE CONSUMPTION OF WATER AT DIFFERENT HOURS OF THE DAY IN A COUNTRY TOWN OF ABOUT 50,000 INHABITANTS, SUPPLIED UNDER THE SYSTEM OF CONSTANT SERVICE.

AVERAGE OF THE SIX WORKING DAYS.

	Proportionate Consumption in the Hour, the Average over the whole day being 100.
From 6 to 7 A. M.	104
" 7 " 8 "	193
" 8 " 9 "	128
" 9 " 10 "	215
" 10 " 11 "	161
" 11 " 12 "	122
" 12 " 1 P. M.	104
" 1 " 2 "	102
" 2 " 3 "	166
" 3 " 4 "	130
" 4 " 5 "	85
" 5 " 6 "	74
" 6 " 7 "	102
" 7 " 8 "	78
" 8 " 9 "	81
" 9 " 10 "	61
" 10 " 11 "	55
" 11 " 12 "	54
" 12 " 1 A. M.	66
" 1 " 2 "	52
" 2 " 3 "	74
" 3 " 4 "	52
" 4 " 5 "	65
" 5 " 6 "	74

The fluctuation in the consumption at different periods of the year will be shown by the following table, taken from Colonel Sir Francis Bolton's published Reports:

CONSUMPTION OF WATER IN LONDON DURING EACH MONTH OF THE YEAR 1883.

	Millions of Gallons per Diem.
January	133.5
February	130.8
March	132.9
April	139.0
May	143.6
June	159.5
July	159.1
August	159.8
September	154.1
October	146.5
November	142.7
December	138.6
Mean of the year	145.0

This shows an excess, over the average, of about 10 per cent. in the hottest months, and a deficiency of about the same in the coldest.

Taking these two tables together, it will be seen that it is necessary, in all towns on constant supply, to provide carrying capacity much larger than is due to the average consumption. For example: suppose the average consumption over the whole year to be 1,000,000 gallons a day, then the average in the summer months will be 1,100,000 gallons. And in some hours of each day in those months the consumption will be at the rate of about 2,350,000 gallons per day, for which the mains must accordingly be prepared.

General Sources of Water Supply.

I now go on to speak of the various modes of obtaining water supplies. There is only one original source, rain; but there are several varieties in the modes by which the rainfall is made available. These are:

1. *Direct Collection.*—We may catch the rain-water as it descends close to the places where we want it, storing it up in suitable receptacles.

2. *Gathering Grounds.*—We may choose a surface of land, and collect the rain-water falling thereon.

3. *Rivers.*—We may take water by pumping from a river of sufficient magnitude, flowing along low ground.

4. *Wells or Springs.*—We may draw upon the stores of water contained in subterranean strata, by sinking wells; or we may collect the same water as it issues spontaneously in springs.

We may say something on each of these plans.

Direct Collection of Rainfall.

First, we may catch the rain as it descends, on the spot where it is wanted. A rain-water butt, collecting the rain from the roof of a house, by gutters and pipes, is a very common thing; and the same plan is often advantageously carried out in large isolated establishments, such as gaols, unions, asylums, etc.*

In Venice, the greater part of the water supply of the city is obtained in this way. Many people will recollect two handsome artistic well-curbs in the court of the Ducal Palace. These are openings into underground reservoirs made to receive and store the whole of the rain that falls on the buildings; and there is an ingenious arrangement by which the water is made to pass through a filter before it gets into the well.

But it is in India and other tropical climates that the direct collection of rainfall has the widest application. In these places a very large quantity of rain descends during the monsoon, *i. e.*, four months of the year, whereas during the other eight months not a drop falls. Rivers are only available in their immediate locality, streams become in the dry season mere sandy beds; wells are only locally and partially efficient, and the great trust is in the system of tanks. These are open excavations made in the ground in great numbers and often of large size, which become filled by direct rainfall during the monsoon, and store up the water for use during the rest of the year.

Gathering Grounds.

But the more common way of making a direct appropriation of rainfall is by collecting it on the surface of a tract of land, which is called a gathering ground.

To illustrate how this is done we will imagine a tract of land lying high in a hilly district, and on which a fairly large quantity of rain falls. By reason of the natural slope of the various portions of this area, the water will run off it in little rills and rivulets, which will ultimately combine into one principal stream, draining the whole area. Hence, by taking possession of, and utilizing this stream, we in reality collect and utilize the rain-water falling over the whole of this drainage area.

This is done by forming a *reservoir* upon the stream in question. The stream will naturally flow in a little valley, and, by choosing a convenient place, and constructing an embankment across this valley, the waters of the stream will be dammed back and impounded in the trough of the valley above the embankment, and so will form a reservoir, containing a store of water. This store is made available for the supply of a town, by simply laying down a conduit from the reservoir to carry it to the place where it is required. When the reservoir

* 1,000 square feet of horizontal roof surface, catching 24 inches of rain per annum, will, if none of the water is lost, yield 34 gallons per diem.

is full, the superfluous water will overflow by a waste-weir and conduit (called a bye-wash) down to its original channel.

This mode of obtaining water supplies is very common in hilly districts, and numbers of large towns, particularly in the manufacturing districts of Yorkshire and Lancashire, are supplied in this way.

The formation of large reservoirs of this kind is a very responsible and difficult thing, only to be undertaken by engineers of great experience and sound judgment. The first object is to secure the absolute safety of the dam, seeing the frightful consequences that must ensue if it should give way, suddenly letting loose such an enormous mass of water, from a great height, down upon the country below. When the reservoir is full the pressure upon the dam is very great, and although, considered as a mass, it may be stable enough, yet the water by penetrating among its loose materials may gradually endanger its cohesion ; or the natural ground against which it is formed may be treacherous, and give way.

Such failures have occasionally happened, one of the most disastrous of them being the bursting of the dam of Dale Dyke Reservoir, above Sheffield, in the year 1864. By this accident above 100,000,000 cubic feet of water were suddenly let loose, rushing with tremendous violence down a narrow valley and through the town of Sheffield, and causing the loss of two hundred and fifty lives, with the destruction of property to the amount of hundreds of thousands of pounds. No wonder that the inhabitants of valleys in which water-supply reservoirs are situate should feel anxious about their construction, and about the competence and skill of their builders.

Then the reservoir must not only be safe but it must be sound, *i. e.*, perfectly water-tight. Leaks must be prevented, not only in the artificial dam, but also in the whole interior surface of the reservoir, the strata in these mountainous countries being often fissured and treacherous.

It is impossible for me to offer any explanation of how an engineer is to produce a good, safe and sound reservoir, seeing that in the first place it is not the purpose of these lectures to enter into engineering details ; and secondly that the difficulties to be encountered are so varied in their nature, and depend so much on local circumstances, as not to admit of any such notice as would be practicable here.

Supplies from Lakes.—Some large towns are supplied from natural lakes. This mode of supply is in reality the same as that just described. The lake is fed by streams from a gathering ground, and it is in fact only a reservoir, made by nature instead of by art. Or to put the comparison in another way, a reservoir is only a lake made by art instead of by nature. When, however, a lake is used for water supply, something must be done to it artificially to fit it for its work.

The popular notion that, given a lake, you may draw water without limit from it, as you might out of the sea, is a delusion. The essence of a reservoir is that it is a store of varying content: it can be filled when the supply comes to it, and when there is no supply it can be drawn down. Now a natural lake has usually a level pretty nearly uniform. To fit it for water supply this must be altered; it must be capable of being drawn down for the use of the district in times when there is no rain. This being done, we may consider the two cases identical.

Yield of Gathering Grounds.—The quantity of water which may be obtained from gathering grounds is a very complicated and difficult study. At the same time it is exceedingly important, for on the accuracy of its determination must depend the sufficiency of the supply to the inhabitants of a town. Cases have unfortunately not been uncommon where towns supplied from gathering grounds have been in great distress for water. In the long drought of 1868, Manchester, Bradford, Halifax, Sheffield, Preston, and many other towns, suffered severely, and the same thing occurred again last year, almost amounting in some places to a water famine.

The causes lie in the uncertainties of the meteorological conditions in our preeminently uncertain English climate, and they necessitate a most careful study of the problem by the engineers and promoters of water undertakings.

We can ascertain the area of the gathering ground with the greatest accuracy. But the difficulties arise in estimating the quantity of *rainfall* we can get off it. For a long time the information gathered about this most important element of engineering calculation was very scanty. But of late years, thanks to the indefatigable labors of Mr. Symons, there have been collected, in his annual Reports on British Rainfall, a series of data of the most useful and valuable character.

The rainfall varies exceedingly at different times and in different places.

As to the variability at different times, I shall have hereafter to speak more fully.

To illustrate the variation in different places I may refer to an admirable map of the rainfall in the British Islands, prepared by Mr. Symons, which is published in the Sixth Report of the Rivers Pollution Commission, 1874. This shows that the annual rainfall in different parts of the country varies from 25 to 75 inches. But the extreme variations run much higher. For, taking single stations in 1883, the rainfall at the Stye, in Cumberland, was 190 inches, at Clacton-on-Sea, in Essex, it was only 18.7 inches—one ten times greater than the other.

These places lie wide asunder, but even in the same locality the rainfall will vary materially in sites only a short distance apart. And hence it is always desirable that, before any important proceedings are taken, the rainfall upon a tract of ground proposed to be used as a catchment area should be ascertained, as far as possible, by direct observations upon the ground itself.

Suppose, then, we have taken such observations, say, for a year, and suppose, for example, we find that the total annual rainfall over the area of our gathering ground amounts to 44 inches. Our first difficulty is that we cannot gather, for storage and use, anything like the total quantity of rain that falls. There is always a loss, which occurs in several ways.

In the first place, a part of the water will be returned to the heavens by evaporation ; then another portion will be absorbed by the vegetation growing on the land ; and, thirdly, another portion will percolate through pores and fissures of the earth, to enter subterraneous strata, and find its way out at a distance in springs.

Now, these three sources of loss vary exceedingly under different circumstances and at different times. They are naturally greatest in hot and dry weather. A shower occurring at such times will often contribute nothing at all to the reservoir, whereas, when the atmosphere is cold and damp, and the ground already wet, nearly the whole may become available.

The loss by percolation will vary materially according to the nature of the geological formation of the district. In chalk districts, for example, the whole rainfall is often absorbed into the earth, there being no surface streams whatever; whereas, on compact rock formations, the percolation may be almost nothing.

And then, much depends upon the inclination of the surface. If the ground is very flat the water will run off slowly, and will have more time to evaporate. In steep ground it will rush down rapidly into its receptacle.

In the face of these irregularities it would be impossible to give any accurate rules. All that can be done is to form some general notion of the results of experience.

Dr. Dalton, an eminent meteorologist, estimated that, taking the whole of England, only about one-third of the rainfall found its way into the sea, and this is estimated to be about correct as regards the Thames. But in mountainous districts the proportion of the rainfall flowing down the streams is greater, being often one-half or two-thirds, and sometimes even more.

It is usually considered more correct not to assume the losses as proportionate to the rainfall, but to estimate them at a fixed quantity, whatever the rainfall may be.

This quantity will vary from about 12 to 18 inches per annum, according to the nature of the ground. Steep ground of compact rock will give the minimum, flat ground of more permeable rock the maximum deduction, as in the basin of the Thames, where the rainfall is about 27½ inches. and the loss is about 18 inches.

Hence, out of our 44 inches assumed rainfall we must make this deduction before we can estimate the quantity of water available. For the sake of example, call this deduction 14 inches. This will leave 13 inches in the year available for use. Having got this, it is only a matter of simple arithmetic to calculate, knowing the area of the catchment ground, how much water we can get in that year.

There is a very simple rule for this:

If R=rainfall in a given year in inches;
E=estimated loss by evaporation, etc., in inches;
A=area of gathering ground in acres;
then Cubic feet of water per annum= 3,630 A (R−E),
or, Gallons of water per diem = 63.15 A (R−E).

But now we come to another complication, which leads us to consider the use of the reservoir.

During the year that we have taken the rain will fall irregularly, some months will be wetter and some will be drier. But the supply must be uniform, or nearly so, and hence the reservoir must be of such size as to equalize the quantity, storing sufficient water in the wet months to tide over the drier ones. To illustrate this I may take an example out of Mr. Symon's tables:

Rainfall at Brecknock, in South Wales, for every Month in the Year 1883.

	Inches.
January	7.06
February	10.19
March	1.67
April	1.20
May	2.22
June	5.14
July	3 73
August	1.25
September	6.04
October	5.81
November	5.55
December	1.88
Total for the year	51.74
Mean monthly fall	4.31

I have calculated what size of reservoir would be required to equalize these irregularities, so as to yield day by day a quantity of water equal to the average of the year, and I find for this purpose no less than about one hundred days' storage room would be required.

But there is another and a greater complication. In our simple hypothetical example we have assumed that we get, by our rain-gauges, the amount of rain falling in a single year. But this in only very imperfect information, seeing that the rainfall varies materially in different years. In some districts the variation is enormous. At Windermere, where the average of twenty-two years gave 79.85 inches, it sometimes reached 116.26 inches, and sometimes went down to 47.24 inches. But the worst feature of the variation is that there will sometimes occur several consecutive dry years.

Mr. Symons, in his report for 1882, has given a valuable table illustrating this. He has collected, with vast labor, the records of rainfall at forty-five stations, during 43 years. I may give the following as an example:

Annual Rainfall at Uckfield, in Sussex, for Forty-three Years.

	Inches.	
1840	22.30	
41	36.30	
42	24.60	6 years average 24 in. (1842–47)
43	30.09	4 years average 22 in. (1844–47)
44	23.37	
45	23.03	
46	25.11	
47	17.58	Minimum.
48	38.03	
49	29.33	
1850	28.62	
51	24.26	
52	50.55	Maximum.
53	31.70	
54	23.15	
55	23.80	
56	33.59	
57	31.74	
58	19.36	
59	33.48	
1860	42.46	
61	28.35	
62	30.01	
63	25.74	
64	23.48	
65	38.97	
66	33.79	
67	30.48	
68	30.51	
69	28.57	
1870	24.99	
71	25.64	
72	38.64	
73	30.06	
74	24.65	
75	29.02	
76	33.37	
77	39.58	
78	31.25	
79	33.00	
1880	31.79	
81	33.05	
82	35.90	
Mean of the 43 years.	30.08	

It will be seen that while the average of the forty-three years is a little over 30 inches, the annual fall sometimes reaches above 50 inches, and sometimes is as low as $17\frac{1}{2}$ inches. Moreover, there were six years together when the average annual fall was only 24 inches, and four years together when it was only 22 inches.

It will be easily inferred from this, that a single year's datum of rainfall, which we have assumed in our previous example, will be of no use. It may have been a wet year or a dry year, or anything between. We must have, for our gathering-ground, data of the rainfall over a large number of years, embracing, if possible, all the variations of wet and dry.

How, then, are we to treat these data when we get them? We can, of course, deduce from them an average rainfall for the whole series But this, also, is no proper guide, unless upon the condition that we can store over all the excesses of the wet years, to supply the deficiencies of the dry years.

Now, I have taken some trouble to get a rough notion what size of reservoir we ought to have to equalize the forty-three years' rainfall shown in the above table, and I find it would require a store of something like 900 days' supply. It is altogether unreasonable and impossible that a water-works undertaking could be burdened with such a monstrous construction.

Mr. Hawksley has often urged this with great force. He points out that, however large, in reason, the reservoirs may be made, in wet seasons they will be full; and, as floods come down chiefly in wet seasons, they will then simply run to waste down the bye-wash—they cannot be stored; and as these floods help materially to swell the average, this average cannot be obtained from the reservoirs.

Mr. Hawksley gives, as the result of his long study of the question, and great experience, that it is impossible, practically, to spread the equalization over a longer period than three years. And, for the sake of safety, the three years taken for calculation must be the three driest years that come together.

Mr. Symons has deduced from his large table some general results which appear to prevail, and they agree fairly well with data laid down by Mr. Hawksley in 1868, before the Duke of Richmond's Commission.

It is found that the wettest year will have a rainfall nearly half as much again as the mean.

The driest year will have one-third less than the mean.

The driest three consecutive years will each have one-fifth less than the mean.

Or, more exactly, if R_m=mean annual rainfall over a long series of years, then

Rainfall in the wettest year
$$=1.4 \text{ to } 1.5\times R_m.$$
Rainfall in the driest year
$$=0.63 \text{ to } 0.67\times R_m.$$
Mean of the driest three consecutive years
$$=0.77 \text{ to } 0.79\times R_m.$$

Thus, if Q=daily quantity in gallons, for all purposes, required to be supplied from the reservoir, then

$$Q=62.15A\left(\frac{4}{5}R_m-E\right),$$

which gives the relation between the area of gathering-ground and the quantity it will supply.

But it is further desirable to know the size of reservoir which will be required to equalize the rainfall over the three years selected. For this it is impossible to give any precise rule, it being so entirely a question of experience. But Mr. Symons has again furnished a statement which will be some guide.

The necessary storage will vary in different districts, for this reason, that in wet districts, the extremes, both of wetness and dryness, are less pronounced than in drier districts. Hence, in a rainy country, a smaller reservoir will suffice than in a dry one.

The general judgment of experienced practitioners appears to be that, for large rainfalls, a storage of 150 days' supply, or even less, will suffice; but in drier districts it may be necessary to go as high as 200 days. And this is a provision which may reasonably be borne.

Compensation.—But there is another point that the engineer has to consider in laying out water supplies from a gathering ground.

The essence of the arrangement is, that he takes possesion of a stream; intercepts it from its former course, and turns its water away in a different direction for the supply of a town. But there will be persons residing, or having property on that stream, who will have something to say about this arrangement; and engineers accustomed to such things know pretty well that riparian proprietors in this position have the habit of making themselves pretty loudly heard. They demand what is called water-compensation; and a few words will explain what this means.

Before the reservoir is made, the stream in question will vary exceedingly in its volume at different periods. In dry weather there will be very little water in it; while in heavy rains it will be a torrent swollen to a flood. This variable state of things is very inconvenient for everybody on the stream.

Now when a reservoir is put in, it gives the opportunity of remedying, in a large measure, these evils; for it will act as an equalizer for the stream, just as it acts as an equalizer for the town supply. When the floods come down they are absorbed in the reservoir, and in return for this, the reservoir, in addition to the supply furnished to the town, may be made to give out, also, an equalized supply to the stream in dry seasons. This is called compensation-water.

The quantity of compensation-water to be given may vary according to special circumstances; but in the manufacturing districts, it is usual to allow one-third of the total supply impounded; leaving the other two-thirds for the supply of the town. The quantity Q in the formula must, of course, comprehend both supplies.

It is usual to insert in Acts of Parliament stringent conditions to compel this supply of the compensation-water, and explicit provisions for determining its quantity. The most usual mode of gauging is by the flow over a weir, or through a measured orifice under a given head. But, as these depend on calculation, the riparian owners have, in some cases, demanded a more positive determination; and Mr. Bateman has contrived an ingenious machine for this purpose, which actually measures the water, as a publican would measure a pint of beer. It will be found described in Mr. Bateman's magnificent work on the Manchester Water Supply, p. 178 and illustrative figure.

A gauge-basin is prepared of exact known dimensions, into which the compensation-stream can be turned at any time; and the machine consists of a tumbling apparatus by means of which the stream can be turned into the gauge-basin instantaneously, and can also be diverted from it with equal celerity. By this means the duration of the flow into the basin can be exactly known, and the quantity flowing in a given time can be exactly determined.

Quality of Water from Gathering Grounds.—It is only necessary to say a word or two on this point.

If the grounds lie high, in hilly country, as they mostly do, the water is usually very pure and soft, not having much opportunity of acquiring contamination. If the lands are flatter and lower, the water flowing over them will have more chance of taking up foreign matters, and in these cases filtration is sometimes necessary.

There is, however, one kind of effect to which water, even from the highest land, is liable, namely, to discoloration by peat. Most of these high lands contain, in certain spots, masses of decaying vegetation, in the shape of morasses or peat-bogs. These collect the rain-water like sponges, and when it flows away from them it carries with it small particles of the vegetable matter, which render it brown in color. This is no great detriment to the use of the water; the presence of these brown particles does not render it at all unwholesome; but still it is objectionable to look at.

It is said, and I believe with truth, that this water will bleach if allowed a long run in an open conduit exposed to the light and the air.

And I may here notice an ingenious arrangement contrived by Mr. Bateman for diminishing the collection of brown water in districts where much peat exists. It is well known that the color is worse in the time of floods, when the greater flow of water through the peat bogs washes the vegetable particles out of them. Mr. Bateman has cleverly taken advantage of this fact to effect his object, by a "separating weir," as shown in his beforementioned work on the Manchester

Waterworks (p. 128 and illustrative figure). It consists simply of forming across the stream channel a narrow slit, which communicates below with the clear-water reservoir, or a passage leading to it. When the stream is clear it moves slowly and falls through this slit; but when it is in flood, moving with a higher velocity, it is carried over the slit without falling into it, and flows away by the natural course of the river.

Examples.—Towns supplied from gathering grounds are very common in hilly districts. I need not give any list, or any elaborate descriptions, but I will just name three of the most celebrated cases.

One is the supply of Glasgow from Loch Katrine, which was carried out by Mr. Bateman, in 1859. The loch, lying 367 feet above the sea, forms a large reservoir for the catchment-basin above it, in which the rainfall is very large—70 to 90 inches per annum. To fit the lake for supply purposes, its level was raised 4 feet, and arrangements were made so that it could be drawn down 7 feet in all. thus giving an available storage of 5,600 millions of gallons.

The conduit from the lake to Glasgow is 26 miles in length, of which, 13 miles are in tunnel under hills, and 4 miles are in iron pipes across valleys. It will deliver about 50 million gallons per diem.

The cost of the works was about £1,-000,000 sterling.

The two other large supplies I will mention have rather a curious history. About the year 1869, there was a good deal of discussion as to the water supply of London. An impression was prevalent that the Thames ought to be abandoned; and two projects were proposed for supplying the metropolis from distant sources. One was by Mr. Bateman, from the head-waters of the Severn, in North Wales; the other by Mr. Hassard from the lake district of Cumberland.

In both these places the rainfall was large, and the water of unimpeachable quality, and the designs were both excellent and perfectly practicable. They were referred to the Duke of Richmond's Commission, who, however, came to the conclusion that, for the present at least, the metropolis did not require them; and they ventured a prediction that the fine sources of supply in these districts would probably be found more useful for the large towns nearer to them in the north-west of England.

This has actually occurred. Manchester has taken possession of the Cumberland, and Liverpool, of the Welsh supply.

The supply of Manchester and its outlying dependencies, from Longdendale, laid out by Mr. Bateman, in 1847, has proved insufficient for the growing demand, and in 1879 an Act was obtained for taking water from Thirlmere Lake, close to Hellvellyn.

The lake is but a small one, and to fit it for storage, its level will be raised 50 feet, which will give an available capacity of 1,300 millions of gallons. The rainfall is high—some 75 inches per annum—which at present is all wasted in useless and mischievous floods, and it is estimated that a supply of 50 million gallons per day may be obtained.

The natural outlet of the lake is to the north; but, by boring under Kirkstone Pass, a discharge will be effected at the south end, and this will be brought to Manchester by a conduit a hundred miles long. It will also supply, if necessary, towns along the line.

The lake is 533 feet above the sea, and the height gives ample fall.

The estimated cost of the work is £3,-500,000.

Liverpool has been supplied for many years, partly by old wells in the sandstone, but chiefly from gathering grounds at Rivington, laid out by Mr. Hawksley many years ago. But here also the demand outgrew the supply, and larger sources had to be resorted to. The gathering grounds of North Wales were fixed on, and the works of supply are now in progress.

The River Vyrnwy, one of the head-waters of the Severn, is embanked in a favorable spot, forming a great artificial lake of 1,100 acres area.

The height is about 825 feet above the sea, and the water will flow to Liverpool by a conduit 67 miles long, including 4 miles of tunnel.

The quantity to be obtained is estimated at 40 million gallons per diem.

Rivers.

The third mode of making rainfall available is by drawing it from a river of some magnitude, flowing through low ground. It is a very common thing to find large towns situated on or near large rivers. Probably one of the motives for establishing them there may have been to furnish them with a convenient water supply; but at any rate, when a river of fresh water flows close to a town, it offers, *prima facie*, the most obvious source for this purpose, and many towns are so supplied.

We may say something as to river supplies, both as to quantity and quality.

In the first place, as to quantity. The capability of rivers in this respect was investigated at some length by the Royal Commission of 1869, having reference specially to the Thames. They pointed out that the river was fed, not so much by the drainage of rain from the surface, as by the delivery of water through springs from the large stores laid up in permeable strata; and that this fact gave a permanence of flow, which was of great importance in water supply. As a proof of this, it was remarked that during long droughts, when many towns depending on catchment-supplies were in great distress for water, the Thames and the Lee seemed not to have been diminished below the ordinary flow of dry years, a result entirely due to the equalizing effect of the great subterranean stores contributing to them. The Royal Commission reported "That the abundance, permanence, and regularity of supply, so important to a large town, are secured much more efficiently by the great extent and varied geological character of a large hydrographical basin, than by the very much more limited collecting areas available on the catchment system." And this remark will apply to river supplies generally.

In regard to quality, however, there is much more to be said, as it is on this ground that objections are usually raised to river supplies. We may exclude from consideration those rivers which are specially fouled by manufacturing operations, as in Lancashire and Yorkshire, confining our attention to rivers which flow chiefly through open country and agricultural lands.

Referring back to my remarks on quality generally, I mentioned three classes of impurities; and these have all to be considered in regard to rivers.

First, there is the class of impurities held in mechanical suspension. All rivers of any magnitude are liable to be more or less turbid, by the surface drainage of lands; but, as I have explained, such impurity can always be removed by efficient subsidence and filtration.

Secondly, as to mineral matters in solution. A river will almost always contain lime, from its being largely fed by springs; but this is so modified by the surface drainage, that the hardness is usually very moderate; and in this particular, therefore, no great objection generally arises.

It is the third class of impurity, namely, organic contamination, which is of the most importance. And I have purposely postponed the consideration of this till now, because it is in river supplies that this kind of contamination is most to be feared.

I repeat that this, like all other points regarding quality, is a matter specially for chemists, and that the best professional advice must always be called in before a final judgment is arrived at as to the propriety of using a river supply. But I also repeat that a water-engineer is bound to have a certain general knowledge of the subject; and taking well-ascertained data as his guide, he is expected to form, by careful observation and common-sense reasoning, at least some preliminary judgment on the case before him. All, therefore, I profess to do, is to specify a few points that may reasonably occupy the engineer's attention in regard to the organic contamination of river water.

In the first place, we must not be frightened at the name. There is often a horror of the very idea of "organic contamination" in drinking water. But this, taken generally, is a mere foolish prejudice. We must recollect that all our solid food is organic, and almost all our drink, except water, depends on organic matters for its pleasantness and its usefulness. Hence the mere fact of water containing organic matter means nothing against it. We must discriminate what kind of matter it is, and where it comes from.

Water washing over land surfaces, covered with vegetation, must necessarily collect organic particles. But these will for the most part be harmless, and when filtered the water will be perfectly wholesome. Even decaying vegetable matter, though it may be offensive, is seldom noxious. There is a very common example of this in peaty water, which really comes from decaying vegetation, but which no one objects to, except for its color.

The contamination to be guarded against is that of animal origin. River water is liable to be polluted with the excreta of animals, sometimes in the worst form of concentrated town sewage. No doubt this kind of contamination is both disgusting and dangerous ; and it would offer a most powerful objection to the use of rivers as sources of water supply, were it not for a great principle of nature that tends strongly to counteract its evils.

This principle has been fully explained by the chemists. The noxious substances forming animal excreta are, generally speaking, exceeding instable in their chemical composition ; and in the presence of oxygen they are constantly tending to change, this change involving a destruction of their noxious properties, and their conversion into inert, harmless compounds. This change or oxydation will, we are told, be certainly brought about by exposure to the air, or to the action of water, which almost always contains free oxygen enough to produce the effect required.

Nobody, I believe, disputes the existence of this purifying influence ; indeed, if it did not work daily, the civilized world could not go on. The only points of disagreement are as to the extent of its action, and the time necessary to effect it in certain cases.

Now, keeping this principle in view, let us consider what are the circumstances that give rise to the organic contamination of rivers.

It is not uncommon to hear it said that a river must be necessarily contaminated with the excreta of the whole of the inhabitants living on its area of drainage. But such a statement is a gross exaggeration, and ignores the purification principle altogether. What is the position of the inhabitants on the drainage area? The fact is that a very large proportion of them live in what may be called the country, *i. e.*, widely and sparsely dispersed over the land, and not collected in towns. In the basin of the Thames, for example, above the tideway, less than one-fourth live in towns of two thousand inhabitants and upwards, three-fourths being spread over the wide surface of the country.

Now, everybody who has seen life in these country districts must know that the excreta both of the human and of the lower animals are, as a matter of ordinary economy, disposed of directly upon the land, and it is notorious that such a disposal is the most favorable for their complete oxydation, and for the speedy destruction of their noxious properties.

It is generally admitted that by the application of animal excreta to land, in the manner known as "sewage irrigation," if laid out and managed to the best advantage, the noxious elements will become oxydized and destroyed. It follows, therefore, that, so far as regards all these country-produced excreta, the whole drainage area forms one immense sewage-farm, on a scale of efficiency sufficient to purify hundreds of times the quantity thus put upon it. Hence, so far as this element of pollution is concerned; no great fear need be entertained as to any dangerous contamination of the river water.

Again, we often hear about the pollution by the washings from manured lands ; and even the sheep, cattle and birds are accused of poisoning the river water. But here again the same principle applies ; the excretal matters being exposed to oxydation and destruction in the most favorable way.

That this reasoning is true is proved by the most ordinary common-sense considerations. These causes of organic contamination have been at work for ages ; ever since the lands have been inhabited and cultivated. And during the whole of this time the rivers have been used as sources of water supply to the whole country, and nobody has been poisoned ; in fact we may say, in regard to the bugbear of universal organic pollution, in the words of one of our most entertaining poets—

> "In spite of all this terrible curse,
> No one has seemed a penny the worse ! "

We must not, however, forget that we have the other fraction of the population to consider, namely, those who are collected in towns lying on the river or its tributaries above our proposed source of supply. For if these towns are systematically drained, and discharge their sewage into the stream, there is undoubtedly introduced thereby an element of contamination of a really serious character.

This cause of pollution is, it must be observed, of comparatively recent introduction. It has brought in elements of offensiveness, and indeed of danger, which have not existed before. While the river was left to natural pollution only, it worked its own natural purification. But now that we take pains artificially and purposely to damage its quality, it is by no means certain that the same result will follow.

But even in this worst of all contaminations, the case is not hopeless. In 1876 an Act was passed to prevent the pollution of rivers; and it is provided that no sewage shall be allowed to flow into any stream until the authorities of the place have used the best practicable and available means of rendering it harmless.

This opens the very large question of sewage treatment, which I cannot pretend to discuss here. I will only allude to the two modes now generally practiced. The best is what I have already mentioned, namely, application to land—by sewage irrigation or filtration. If this process is fully, efficiently, and carefully carried out, all authorities agree that the noxious qualities are practically destroyed, and the water is restored to a state closely approaching its original harmlessness. The other process is by chemical precipitation. By this the worst parts, the suspended solids, are removed, and so a great deal of good is done; but the effluent will still be impure.

However, we must not leave out of sight the great saving element of the purifying power of the stream. For if, after either of these processes, sewage contamination is still introduced, yet provided a sufficiently long run, and a sufficient time, are given, nature will probably do what is necessary to complete the purification.

Several processes will assist in this work. In the first place, a portion of the organic matter will be removed by fish and other animal life. A further portion will be absorbed by the growth of aquatic vegetation. Then we have, finally, the decomposing power of the fresh water in the river, which always contains much free oxygen, eager to attack the instable organic compounds the moment they enter. And this action is very much facilitated by the motion of the stream, particularly if it falls over weirs.

Chemists differ as the extent and as to the speed of this purifying action, but, as a matter of practical observation, its beneficial effect is most positive and unquestionable. In many cases where a mass of sewage has been bodily discharged, in its most crude state, into a running stream, no trace whatever has been found of any deleterious matter, either by chemical tests or by practical use of the water, a few miles lower down.

I say this, however, with a reservation as to what is called the "germ" theory. Some authorities have expressed the opinion that if the germs of certain zymotic diseases once enter town sewage, they cannot, by any practicable treatment, be destroyed or removed, and that water receiving such sewage should always be considered as dangerous, and improper to be used for drinking. On the other hand, there are many authorities who think this theory merely fanciful, and unsupported by evidence. It is beyond my province to discuss the point. I only mention it, and it must have the consideration it deserves.

On the whole, however, I believe it to be a sound conclusion that, although every care and caution should be used in adopting river supplies (which are often so very convenient), they ought not, by unreasoning prejudice, to be tabooed as ineligible. It is the business of the engineer to make the great powers of nature subservient to our use and convenience; and the purifying power of nature is certainly one that he should take advantage of if he can.

It is worthy of remark that in some cases the water of a river may be taken, not out of the river itself, but out of the thoroughly saturated bed in which it runs. It often happens that the ground through which the river forms its course is gravel, or some open porous alluvial stratum. This is of necessity charged with water, and a plentiful supply may be drawn from it, which has undergone a natural filtration. The supply of Oxford is obtained chiefly in this way, and the same thing has been lately done to a considerable extent by some of the London water companies, who find a fine, clear, and ample supply in the gravel beds near the Thames at Hampton. The water in these cases does not necessarily come from the river; it may often consist of springs and subterranean drainage waters, which are flowing towards the river, and are intercepted on their way.

Supposing a river to be chosen as the source of a town supply, the operations of taking it are so simple as not to require any detailed description. The water is first allowed to deposit its grosser particles by subsidence in large tanks, after which it is filtered, in the manner I have already described, and is then pumped up to the town.

Wells.

The modes of utilizing the rainfall which we have hitherto considered, have all been founded on the supposition that we take the water on the surface of the ground. But some portion of the rain will percolate through pores and fissures of the earth, and will store itself subterraneously in permeable, or, as they are termed, water-bearing strata. In some districts where these strata form the surface beds, the rain disappears with marvelous rapidity, and in these districts, consequently, there are few or no surface streams. On the chalk downs, for example, there are no rivulets in the valleys; the water that would feed them has all gone below.

The water is stored in these strata in two ways: First, in the pores of the rock itself; and when the material is of an open grain, the quantity of water held in it is much more than one would suppose. But this storage is largely augmented by cracks, fissures, and hollows. These are very important, for they serve not only as reservoirs, but as drains to the substance of the rock generally. And it is by tapping these fissures that the most plentiful supplies are obtained.

The most common mode of making use of subterranean waters is by the old plan of sinking wells.

There is a marked distinction to be drawn between shallow wells formed in superficial ground, and deep wells sunk into the lower subterranean strata. Shallow wells are exceedingly common and exceedingly useful. The alluvial beds lying so largely on the surface of the earth receive water very readily, and wells sunk therein form the chief sources of supply in country places generally.

Now, although the water of surface wells is often not very good, yet, if the strata are not liable to be specially contaminated with noxious refuse, it may be safely used. But this condition is not always present. Even in an isolated farmhouse or country residence, there must be a cesspool or similar receptacle, and there is danger, unless great precautions are taken, of liquid from this penetrating the strata and getting to the well.

In towns, this kind of contamination is much more probable, and surface wells become, consequently, especially dangerous, so much so as to be generally prohibited for drinking purposes by health authorities. The alarming outbreak of cholera in Soho, some years ago, due to a contaminated surface well in Dean Street, will long be remembered.

But deep wells, drawing their supplies from strata lying low in the earth, are in a different category, and form excellent sources of water supply.

In some cases a deep borehole will tap a water-bearing stratum covered by impervious beds, and the water, being fed from higher levels, will rise up the borehole, sometimes above the surface of the earth. This is the phenomenon called an Artesian well, with which all will be familiar. But wells of this kind are exceptional. The ordinary well is a large shaft sunk into a water-bearing stratum, where the water lies at a low level, and has to be pumped up to the surface.

The two most important water-bearing strata in England are the chalk and the new red sandstone, and many towns are supplied from them.

We may consider a little what takes place in regard to the water in subterranean strata. It is not stationary, it tends to move away toward low points, where it can find an exit in springs, or into low-lying rivers, or into the sea. And, as a consequence of this motion, it is found that the line of water level within the strata is always slightly inclined toward the points of discharge, the angle of inclination representing the head necessary to force the water through the interstices of the rock. In the *Proceedings* of this Institution, vol. ix., p. 154, will be found an instructive section of the chalk strata near London, showing the water-line, inclined, as I have described, towards the Thames and the Colne. The inclination of the water-line varies, in this place, from about 13 to 26 feet per mile, according to the closer or looser texture of the material, but in many other places it is more rapid, sometimes reaching 40 or 50 feet per mile. The levels of the water in these cases are known by careful observations in wells sunk into the strata at various points.

It is instructive to note the effect that will be produced when we begin to pump out of a well. Before the pumping begins, the water will stand at its normal level; but when the pumps are set to work the surface of the water in the well will immediately descend. The reason of this is, that to supply the well, the water must flow into it from the neighboring parts of the strata, and to enable it to do this, its surface must have an inclination to give it the necessary head to overcome the friction through the interstices. This produces a conical depression all around, the depth and extent of which will adjust itself according to the quantity of water pumped, so that, when this adjusted level is attained, the pumping may go on at the same rate without further depressing the water level. But, if the rate of pumping is increased, the water will be further depressed, till it finds its proper level as before, at which it will remain. There will thus be found a stationary level of water in the well corresponding to every given rate of pumping, so long as this does not exceed the possible yield.

At the same time as the water-level in the well becomes more and more lowered, the area of the cone of depression extends farther and farther around, until it may reach a considerable distance; and this is the reason why a certain rate of pumping from one well may lower the level of water in another well in the neighborhood; which simply means that the cone of depression belonging to the first well has extended so far as to reach the second well. Cases of this kind are very common, and sometimes give rise to a good deal of trouble.

In order to increase the facility of getting the water out of the strata, it is customary to drive tunnels from the well in various directions, so as to enlarge the area of collection. A good example of this is found in the Brighton Water-works, of which an account has been given by Mr. Edward Easton, in the *Transactions* of the Brighton Health Congress, 1881, p. 48.

Brighton is surrounded on three sides by chalk strata, which absorb a very large quantity of water. The level of the water can be easily traced by wells, and it is found to rise gradually from the sea at the rate of about 40 feet per mile; this slope representing the friction of the current flowing down gradually into the sea, as it is replenished by fresh stores, either from the rain above, or the chalk strata behind. Two wells were sunk to the depth necessary to reach the water level, but these alone did not furnish sufficient water, and tunnels or adits were driven to increase it. It was found that the chalk was largely fissured, the fissures mostly extending longitudinally from north to south, indicative, probably, of the erosion of the rock by the subterranean flow of water in that direction. Advantage was then taken of this fact by driving the tunnels from east to west, so tapping the fissures successively at right-angles, and the result was a very copious supply. The quantity pumped is about $3\frac{1}{4}$ millions of gallons per diem.

In regard to the quantity of water which may be got out of a well no rule can be given. Some people have fancied that (as I have said in regard to lakes) these subterranean reservoirs contain an unlimited store, and may be pumped off *ad libitum*. I need hardly say here that this is a delusion; the only source of supply is rain, which gets into these strata from their exposed surfaces, and the yield of a well must always depend, first, on the amount of rain which the strata can collect, and, secondly, on what portion of this can be enticed into the borehole. Neither of these can be determined beforehand, and, therefore, the quantity to be got must be a matter of experience.

The water obtained from wells is usually bright and clear, and free from organic matter. This is the result of the natural filtration it has undergone. But it is generally rather hard, and is well adapted to treatment by the softening processes I have described in a former part of my lecture.

Springs.

Finally, as a mode of obtaining water, we may make use of springs.

The nature of a spring is familiar enough to those who have studied geology. It is simply a place where the water stored in a subterranean stratum finds access to the surface of the ground at such a low level that the head of water lying above it keeps up the discharge.

There isnot much to say about supplies obtained in this way. The springs are simply collected and conveyed to reservoirs for distribution. One of the most magnificent examples is the New River, a conduit 40 miles long, constructed by Hugh Myddleton, in 1613, to bring into London the clear waters of springs at Chadwell and Amwell in Hertfordshire.

Lancaster is supplied by springs in the high moorlands of Wyresdale, 8 or 10 miles from the town, the waters being intercepted by small pipes, and brought down by large mains. The works for this purpose were originally designed in 1852 by Sir Robert Rawlinson, and have since been extended by Mr. Mansergh.

Malvern is also a good example. A great many springs were found to be issuing from the sides of the well-known hills in the neighborhood, and have been utilized by Mr. Hawksley, so as to afford an ample supply of water of the purest kind.

In regard to the quantity obtainable from springs, engineers ought to be very cautious, for there is no means of determining *a priori* how their flow may vary, and in dry seasons they may fail altogether.

Internal Distribution.

Having now gone over the several modes of obtaining water for town supplies, I pass on to a branch of the subject which applies to all these modes alike, namely, the distribution of the water within the town.

The first step in this usually is to bring the water to reservoirs constructed near the town, at such elevations as shall allow it to flow by its own gravity throughout the district. These reservoirs are called " service " reservoirs.

If the water is obtained from a gathering ground, the source will usually lie at such an elevation that the water may flow down along a conduit from the catchment reservoir into the service reservoirs. But, if the supply is obtained from a low-lying river, or from wells, it must be forced up to the service reservoirs by pumping power. Such is the case in London, where steam-power to the amount of 17,200 H.-P. is in use.

I might here go into the subject of pumping-engines and pumping-machinery, but this is hardly necessary, as the subject has often been discussed before the Institution. I will only make two remarks of a very general character.

In the first place, in pumping through a long and large main, it is most desirable to keep the current uniform and regular, avoiding shocks or sudden changes of velocity, which are very trying to the metal, and often cause bursts. For this reason it appears to me that double-acting engines, regulated by a fly-wheel, are to be preferred to single-acting ones of the Cornish type. The Cornish engine had, many years ago, a justly-earned reputation for superior economy; but now that the use of steam is better understood, this no longer exists, and I cannot see any other motive for the retention of this form of engine.*

* The history of the application of the Cornish form of engine to water-works purposes is curious. Some half century ago the engineers of the center and north of England became aware of the reports published from time to time of the extraordinary economy of the pumping engines in the mines of Cornwall. These reports at first obtained no credence, and even when they were found to have some foundation, the most singular attempts were made to explain them away. In the midst of this controversy, Mr. Thomas Wicksteed, the Engineer to the East London Waterworks Company, determined to throw light on the question by buying an engine in Cornwall and setting it up to work on his own premises, where it could be thoroughly tested and examined. The result was fully to establish the truth of the great economy claimed, and so arose the idea of the superiority of the Cornish form of engine for pumping purposes.

When, however, the working of the engine came to be investigated, it was found that the economy was due chiefly to the large amount of expansion made use of, combined with some other modes of economizing heat; and there appeared no reason why, by proper measures, these might not be as efficiently carried out in other forms of engine. Accordingly, when the new Lambeth Water-works were designed, in 1848, Mr. James Simpson, the engineer, commissioned Mr. David Thomson and myself to endeavor

The same principle of regularity of motion also dictates a preference for a particular form of double-acting pump, called the "bucket-and-plunger" pump. It is simply a lifting bucket-pump, the rod of which, passing through a stuffing box at the top, is enlarged to one-half the area of the pump-barrel. The effect of this is that in the down stroke the rod acts as a plunger, and expels an equal quantity of water to that effectively lifted in the up stroke. I do not know who invented this ingenious contrivance, but it was made for the Lambeth Water-works pumping engines by Messrs. Simpson & Co., in 1848. Its advantage is, that although the pump is double-acting, the motion of the water through it is always in the same direction; whereas, in the ordinary double-acting pump it is reversed in the barrel at each stroke. Owing to this peculiarity of the bucket-and-plunger pump, it is possible that the motion of the water may continue, to some extent, at the dead points, and under certain circumstances I believe that the curious result has occurred of the pump delivering more than its calculated quantity.

There is another point in regard to pumping machinery worth mentioning, that is, the necessity of duplication. Everybody knows that, in spite of the utmost care in the manufacture, accidents will happen, and hence a duplicate provision of engine and pumps is an absolute necessity where the supply of a town is at stake. Such a provision is also highly expedient and economical, in order to give proper intervals of rest for cleaning and repairs.

It sometimes happens that a town lies in such flat ground that no elevated site for service reservoirs can be found. In this case a tower may be built, and a reservoir placed on the summit, forming what the French call a "chateau d'eau." Such erections are, however, expensive, and in some cases the plan is adopted of pumping directly into the distributing mains, so giving the necessary pressure by steam power, and not by the gravitating head from a high-service reservoir.

This, however, is both a difficult and a disadvantageous plan. It is difficult because of the constantly varying consumption, which renders it troublesome to regulate the working of the engines, so as to adjust the quantity pumped to the draught on the mains. It is, moreover, disadvantageous to supply a town by direct pumping, because this plan is unfitted to give a large and free supply on a sudden emergency in case of fire. High reservoirs will do this naturally, being always ready, if kept properly filled, as careful water-works authorities will take care they always are, particularly in the night, when fires are most likely to occur. It is obvious, also, that they provide for fluctuation in the town consumption, while they allow the engines which supply them to work at uniform speed and uniform pressure, the most advantageous conditions in every way.

Sometimes, when there is a small high-service reservoir, the two plans are combined. The engines pump into the town at the same time as they pump into the reservoir, which then acts as a regulator, equalizing both pressure and quantity.

The size of the service reservoir must be sufficient to fit it for the double duty before named, *i.e.*, to regulate the fluctuation of the demand, and to hold a store for sudden emergencies. It is found that these objects will be attained if the reservoir holds from one to one and a-half day's supply.

Service reservoirs, if they are in or near the town (as they usually are), ought to be covered. This has several advantages. It preserves the water from contamination by soot and dirt falling from the air. It keeps the water cool in summer, and will go far to prevent it freezing in winter; and, by excluding the light, it is said to discourage the growth of vegetation, to which some waters are very liable. The London Water Acts require that all reservoirs of filtered water within five miles of St. Paul's, shall be covered.

When a town is very hilly, it is necessary to have several service reservoirs at different levels, in order to avoid too much pressure in the distributing mains at the lower parts of the town. For

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to design engines in which this should be done. The result was the construction of some large engines on the compound or double-cylinder principle, which fully realized the expectations entertained of them. Since that time the compound principle has been further developed, and the superiority of the Cornish form exists no longer.—See Wicksteed on the Cornish Engine; Pole on the Cornish Engine; and a paper in the Transactions of the Institution of Mechanical Engineers, July, 1862.

this purpose the town is divided into zones of different levels, each having its own service reservoir.

From the service reservoirs the water is made to flow by cast-iron pipes (or "mains," as they are termed), which ramify in all directions through the streets, the sizes being, of course, properly proportioned to the maximum quantities of water flowing through them. From these mains the water is carried by communication pipes (usually of lead) into the houses. I need not go into any description of this system of pipes, with all their various connections, valves, and appliances; they will be familiar enough to you.

Constant and Intermittent Supplies.—I must, however, say something of the two systems under which town supplies are given, namely, the intermittent and the constant-service systems.

The most natural and obvious way of supplying water is to keep all the supply pipes constantly charged under pressure, so that, whenever any customer wants water, he has only to open a cock or tap to get it. And, no doubt this must have been the mode attempted when house supplies were first given. But a difficulty would soon arise. The cocks and fittings in the houses, after being in use some time would begin to leak, and there would be a waste of water, which, if it became large, would overtax the powers of the water-works to supply. This evil was so serious, and so very difficult to remedy, that it led to the introduction of an ingenious device to evade it. The water-works people said to the consumer, "We cannot afford to give you a constant supply of water which you allow to run to waste. You shall put up a cistern in your house, capable of holding as much water as you can reasonably use in twenty-four hours. We will fill that cistern for you at a certain time every day, and leave it in your care, and then, if you choose to waste the water, it will be your loss and not ours." This was done in a great many towns. The town was divided off into districts, each supplied from the chief mains by a special service main, shut off by a valve. This valve was opened by a "turn-cock" for an hour or two every day, when all the house cisterns in that district were filled. Thus originated what is called the "intermittent" system of supply. It was a great convenience to the companies, as it not only saved them from the waste, but (if the town was supplied by pumping) it enabled them to regulate the action of their engines with much facility.

But then arose sanitary difficulties. It was found that the storage of water in these house cisterns, which were generally very badly looked after, rendered it liable to contamination, particularly on account of connections with water-closets and drains. Hence, when, some thirty or forty years ago, a great sanitary movement took place, the state of the water-supply of towns served on the intermittent plan was strongly condemned; and it was demanded by sanitarians that the house storage should be abolished, and the water served direct from the mains. It was proved that this could be done, and that the objection as to waste could be got over. I believe that our veteran Past-President, Mr. Hawksley, was the first, or one of the first, to show this. He laid out the supply of Nottingham in 1831, and it has never had any other than a constant supply—so constant that the water has never been shut off since, except for a few hours at a time. Many other towns were afterwards similarly supplied by him. Mr. Bateman also successfully introduced the system at an early period, and warmly advocated it. It being thus proved that the constant service was practicable, the Legislature, when they passed the Water-works Clauses Act in 1847, enacted that, as a general rule, "the supply should be constantly laid on at such a pressure as would make the water reach the top story of the highest houses."

Although, however, the difficulties have been surmounted, yet they have required a great deal of thought, attention and ingenuity to make the system a success. This is most especially shown when it is attempted to change a town or district from intermittent to constant supply. In such a case it would not do simply to turn on the water for the whole day. The waste would be so enormous that no ordinary water-works could meet it—it would simply be turning the water into the sewers. The promoters, therefore, have had to investigate, with the greatest care and perseverance, how this waste arises; to study every cause by which water can run away unutilized, and to meet every such case by attention to the most minute detail. The work of doing this has been much more difficult than is usually supposed, and its successful accomplishment has been a great triumph of mechanical skill. I will endeavor to give, as briefly and generally as I can, some idea of the nature of the defects, and the manner in which they are remedied.

In the first place, the introducers of constant service have convinced themselves that the evil does not arise to any great extent from a willful or even a careless, waste of water by the consumers. If it did, constant supply would be impracticable. No doubt such waste does occur to some extent, but it may easily be kept down by stringent prohibitions and moderate inspection. It is found that, among all classes of the public, there prevails a sufficient sense of propriety to prevent serious waste, which is generally a nuisance and an inconvenience to the consumer.

The principal difficulty in this respect has been the mistaken zeal of sanitarians, who have told the poorer classes that it is a good thing to let water run to waste in order to clear out the drains. This is a gross blunder. It has been pointed out, over and over again, that these little dribblings can have no effect whatever in removing any obstructions or accumulations. The ordinary domestic use of water is sufficient, if properly managed, to keep house drains clear, and as to large sewers, it is the business of the municipal authorities to look after them. The waste of water in a house can do no good, and may do much harm.

The waste to be fought against is due, not to the action of consumers, but simply to defective arrangements in the pipes and fittings. It may arise either in the streets or in the houses, and occurs frequently in both. Let us first consider the house fittings.

In the first place, the pipes may be too weak. With constant service the pressure is high and continuous, and the pipes may give way. Hence, a scale of strengths of pipe must be prescribed.

Then the joints of the pipes are often badly made, and leak. This also must be provided against.

Then the draw-tap is of much importance. The ordinary plug-tap is a very bad thing; it has two defects: First, it shuts the water off too suddenly, causing a jerk and great strain; and, secondly, it soon gets leaky, and the constant dripping from a leaky tap will run away with an enormous quantity of water. The use of this kind of tap is forbidden, and a screw-down tap is always provided; it shuts the water off gently, and, if of proper construction, will keep in order a long time, and may be repaired with great ease.*

The ball-tap, which is necessary to some extent, even under constant service is the source of much waste. There are too precautions against this—first, to get the article of thoroughly good construction; and, secondly, to ensure its being promptly attended to when out of order. This last object is provided for in a particular way. It is forbidden that any cistern shall have a waste-pipe by which the water can run away into the drains unseen. The only overflow must be by a pipe which discharges into some conspicuous place, where the discharge will attract attention and produce inconvenience. This is called a warning pipe, and its action will compel a householder to get the tap repaired without delay.

Then, one of the greatest causes of waste has been the supply to water-closets. The ordinary apparatus, if properly used, does not consume more than a fair quantity; but it is liable, in the first place to get out of order, and secondly, to be grossly abused, by propping up the handle, under the mistaken notion already alluded to, that this is good for the drains. The remedy is an ingenious contrivance called a waste-preventer. It exists in several forms, but the one most generally approved is the divided cistern apparatus, which, I believe, was first designed by Mr. Hawksley. The cistern is divided into two parts, which I may call A and B. A is fed from the main by a ball-cock in the ordinary way, and when the apparatus is at rest there is a com-

* The screw-down tap was invented by Mr. Edward Chrimes, of Rotherham, and was patented by him in March, 1845. Some years ago there was a long and hard-fought dispute before the magistrates of Edinburgh as to the construction of tap proper to be used in constant-service fittings, which resulted in the condemnation of the ordinary plug tap, and the establishment of the screw-down tap as the only suitable thing.

munication open between A and B, which fills B. When the handle of the apparatus is pulled, after using the water-closet, the water contained in B is let down into the pan, but at the same time the opening between A and B is closed, so that no more water can be used than B contains, and therefore no waste can be caused, either by accident or design. When the handle is let go, the communication between B and the pan is closed, and that between B and A opened, which charges B again for another use when required. When this is properly made it will keep in order a long time, and is very easily repaired, and it forms as efficient a flushing apparatus for the drains as can be devised.

This, or something equivalent to it, is the only apparatus that is allowable for a water-closet, under the constant-supply system. All simple cocks and valves are expressly forbidden, not only as allowing waste, but on sanitary grounds also. In the poorest class of houses, where the expense of the waste preventer would preclude its use, it is better, on every ground, to allow the water-closet pan to be flushed down by hand, than to "lay on the water," as it is termed, by an imperfect and wasteful cock or valve.

There are other precautions in regard to baths, hot-water boilers, and so on; but I need not trouble you with further details. I have said enough to give you a general idea of the nature of the precautions used.

These precautions are always embodied in a set of regulations, which are carefully prepared, and which the water authority of any town must have power to enforce strictly and stringently; otherwise the great boon of constant water-supply cannot be given.

But they must be supplemented by another power—that is, a control over the plumbers who do the fitting work; for, in spite of all provisions as to the construction of particular articles, if the work generally is badly done, it may give immense trouble. I am sorry to say that the character of the trade generally is not such as could be wished, and great trouble has been experience on this head, from the difficulty of obtaining any legal control. But the water authorities have generally adopted the plan of keeping lists of "authorized plumbers," who enter into an engagement to conform to the regulations, and to do their work in a proper and creditable manner; and the moral control thus given has been usually found effective.

Then, finally, the water authority must have a reasonable power of inspection, and of inflicting penalties for willful or careless waste. But, as I have said before, experience has not shown that this is, or need be, carried out in an oppressive or offensive way.

These measure have been found to suffice for checking the waste, so far as the house fittings are concerned. But there is another cause of waste more difficult to deal with, namely, from leakage in the mains and service pipes in the streets. The mains often get disarranged by the traffic, and leak at the joints, or the small pipes leading into houses decay or get damaged; and leaks from these sources will often go on for a long time undiscovered, the water finding its way into the drains. This cause of waste is often most troublesome in changing from the intermittent to the constant supply.

The difficulty is to find such leaks, and their discovery has been much facilitated by an operation that was introduced in Liverpool some years ago, and which has been fully described to this Institution by Mr. Deacon. It consists in isolating a certain district, and in ascertaining what quantity of water is used therein, at any given time, by applying, temporarily, a meter on its supply main. This will indicate whether more water is passing than ought to be consumed there, and then, by a detailed examination, the locality where the waste takes place can be soon identified. One means of doing this is ingenious, namely, by placing a "hydrophone," or sounding-bar, against any suspected pipe, when, by applying the ear to the other end of the bar, the passage of water through the pipe can be distinctly heard. This will not only detect street leakages, but may also give an idea whether waste to any serious extent is going on in the houses. The leak-detecting operation here described has been of great utility, and has done much to facilitate the introduction of constant supply.

The history of the London supply in regard to constant service, is curious and instructive.

Until within the last ten years the supply was entirely on the intermittent plan. The usual sanitary question had often been agitated; in many districts the supply was disgracefully bad; the propriety of introducing the constant service had been often suggested, and in the Water Act of 1852 a provision had been made to that effect. But notwithstanding the well-known fact that this system was successfully at work in other towns, the measure was always opposed by the companies, on the ground that the waste would be so enormous as to render the system impracticable. And, in the face of this opposition, nothing was done.

Still, however, the demand for the change was very urgent. It was strongly recommended by a House of Commons committee in 1867, and again by the Duke of Richmond's Royal Commission in 1869; and immediately after this last date the Government, earnestly desirous to carry out the measure, determined to institute inquiries as to its practicability.

They did me the honor to entrust me with the investigation, instructing me to visit several country towns where the system was said to be in effective operation, and to make myself thoroughly acquainted with the facts, and, in particular, with the modes of preventing the waste that was so much dreaded; and, having done this, I was to examine the state of things in London, and report if there were any real obstacles to the application of the system there.

The reports which I made on this matter were published as Parliamentary papers, and are well known to all parties interested in the question.

The general results were these: In the first place, I found that the system was in perfect and successful operation in many towns; that several towns had been and were being successfully changed from the intermittent to the constant system, and that, under this system, the consumption of water was much less than under the intermittent plan in London. I also described fully the causes of waste and the means adopted, with success, for checking it.

In the second place, I described the result of my examination of the circumstances of the London supply, and I endeavored to show that, if proper means were used (which I described in some detail), the constant service might be successfully brought into the metropolis. And I ventured to express the opinion that the change would be attended, in the end, rather with an economy than with a waste of water.

It was a great satisfaction to me to know that this report not only satisfied the Government, but also to a large extent satisfied the water companies. For when, in the following year, a bill was brought in for the purpose of effecting the change, the companies accepted it in a conciliatory spirit, and it became law on the 21st of August, 1871. Under the provisions of this Act, a long inquiry was held in 1872, by Commissioners appointed by the Board of Trade, for the purpose of settling the regulations to be adopted for efficiently carrying out the constant-service system; and, having paid so much attention to the subject, I took an important part in the discussions before the Commissioners. The result was the establishment of the code of regulations now in force.

Soon after that time the change began. It was introduced very gradually, and required much caution; but at the present time nearly half the houses are so supplied.

In some districts I believe the change has effected a reduction in the consumption, but in other places this has not been so, a complaint being made of an increase in the waste. I do not know enough of the facts to give any positive opinion as to the causes of this; but I strongly suspect it may arise from a want of proper control over the plumbers and the fittings used, for I was obliged to point out that the character of the plumbing trade in London was, in my opinion, the greatest obstacle to the introduction of the new system. But I am confident that the difficulty may be got over, and I should hope, for the credit of our London water engineers, that the time will not be far distant when the metropolis of England will be as well supplied as Nottingham and Norwich and Manchester have been supplied for the last quarter of a century.

It cannot be denied that the provisions for constant service involve a little more outlay, both to the suppliers and the consumers; but this is largely outweighed by the advantages to parties. The suppliers have to go to somewhat greater expense in their service reservoirs and in their mains, so as to provide efficiently for the fluctuations in the demand at different times in the day, as I have before explained. But they may reap an enormous advantage in the saving of waste, which will most unquestionably be effected, if the system is carried out vigorously and thoroughly. The experience of all towns where constant service has been effectually acted on is positive, that under this system the consumption may be reduced to the minimum possible, while under the intermittent plan 'it is always extravagant and wasteful.

Then the consumer has to incur a little more cost for fittings of more perfect character and of better quality, but he gets amply repaid, not only in the greater purity and wholesomeness of his supply, but in the freedom from accident, and the less necessity for repair. For, the very essence of the improved fittings is their less liability to derangement and their greater durability.

PERFORMANCE OF STEAM-ENGINES.

By JOHN W. HILL, M. E.

Much has been written upon the subject of steam-engine economy, as affected by various degrees of expansion, in one and more cylinders, and hot disputes have been observed between exponents of high and low expansions, each having proved by experiment that the other was wrong.

Similarly the benefits of steam-jacketing are disputed by many capable, experienced engineers, and compounding regarded as an unnecessary expedient for economy.

It is true that the data upon which these contrary opinions are based, are not from engines alike in all respects, except in the expansions of steam employed, in the use or disuse of steam-jackets, or in the arrangement of single cylinder or compound steam end, but are from different engines of dissimilar powers, operating under different and sometimes widely varying steam pressures and piston speeds, some from steamship performance, others from engines driving mills, and still others from engines pumping water for cities. It is probable in these cases, where low expansion has given better results than high expansion, that the steam pressures or piston speeds have not been favorable to high expansion, or that the condition of the steam, by reason of considerable entrainment, forbid high expansion; or that the cylinders were not properly clothed, assuming that in all other respects the engines were in good condition.

In these instances, where steam-jacketing failed to show an improvement in economy, it is likely that the steam was of poor quality, or the exterior of jackets poorly protected against loss of heat by conduction and radiation, or the grade of expansion too low to make the benefits of steam-jacketing available.

In these instances where single-cylinder engines have given a higher economy than compound engines, it is probable that the grade of expansion for the compound engine has been too low, that the effect of intermediate expansion may have been overlooked in proportioning the engine; that the relative proportions of steam cylinders were not adapted to maximum economy, or that the division of work between the two (or more) cylinders was not fairly made.

It is, of course, assumed that in every instance where the performance of a steam-engine has been the basis of an opinion upon the conditions best calculated for maximum economy, that the engine *per se* and its connections have been in fit condition for test purposes, and that no losses existed which were unknown and unaccounted for.

The writer, from many experiments upon first-class engines for various purposes, ventures the opinion that high grades of expansion, steam-jacketing, and compounding of steam end are desirable, if the conditions under which engines are to work are properly considered in fixing proportions, with the following suggestions as to application.

1st. Expansions: The economy of steam-engines, other things equal, will vary as a function of the expansion, provided the terminal pressure be but slightly below the atmosphere. When, however, high expansion can be had only by producing a terminal pressure much below the atmosphere, then the economy will not be materially increased above that due a lower grade of expansion, while the effective work of the engine will be greatly diminished.

Of two cases of high speed engines with similar initial pressures, say, 90 pounds by gauge, and otherwise, operating under similar conditions, where the first shows an operation of the engine with 20 expansions and 4.75 pounds terminal pressure (absolute), and the second, 8.5 expansions, with 12 pounds terminal pressure (absolute), the economy in the second case will be the highest.

Assuming that steam pressures under existing practice be limited to 140 pounds by gauge, or 154.5 pounds absolute, then maximum economy will be had with 14 to 20 expansions of the steam.

2d. Steam-jacketing will not be found advantageous in single cylinder engines operating under less than eight expansions, nor in compound engines operating under less than ten (10) expansions. Moreover, the external wall of jacket space must be thoroughly protected by a non-conducting covering to prevent abstraction of heat from the jacket steam by the atmosphere.

In regulating the consumption of steam by the jackets, care should be had that not more than 5 or 6 per cent. of the total steam to engine be so expended, otherwise the use of the jackets may show a loss rather than a gain.

Under favorable conditions the consumption of steam in the jackets should not exceed 3 to 3.5 per cent. of the total steam to engine.

3d. Compounding: For engines operating at piston speeds of one hundred to four hundred feet per minute compounding will be found beneficial, but for high piston speeds of 600 or more feet, the single cylinder can be made to furnish the best economy.

In compounding, however, consideration must be had for the number of expansions of steam that will occur. No benefit will be found in compounding for an engine working at six or less expansions.

Of the two steam-engines the performance of which forms the substance of this paper, one is a horizontal tandem compound Corliss engine, built from designs by Mr. Edwin Reynolds, of E. P. Allis & Co., Milwaukee, Wis., and the other, a horizontal single-cylinder Corliss engine, built by Wm. A. Harris, of Providence, R. I.

The comparison between these engines is not made to show that either builder constructs a better engine than his competitor, but to exemplify a few of the previous suggestions upon compounding of steam ends, and ratios of expansion.

The tandem compound engine was constructed by Mr. Reynolds, as an experiment, and placed in the "Daisy Roller Mill," an establishment in Milwaukee, the property of Messrs. Allis & Co.; where the designer had unusual facilities for testing the engine, with a view of securing information which might be made beneficial to his customers in the construction of future cut-off engines.

The writer was employed to test this engine and report its performance to Messrs. Allis & Co., with the results given in the following excerpt from his report at the time:

"The engine is a Reynolds-Corliss of the compound condensing type, with cylinders set tandem—small cylinder nearest the crank. The small cylinder has a diameter of 14 inches and a stroke of 42 inches, and the large cylinder, a diameter of 26 inches and a stroke of 42 inches. Both cylinders are unjacketed; but were protected from loss of heat by a plastic covering encased in a lagging of walnut.

"Two trials were made, one from 8.45 A. M., April 26th, to 4.45 A. M., April 27th, 1882, embracing a period of twenty (20) hours, and the other from 11.45 A. M., April 29th, to 12.00 midnight, same date, embracing a period of twelve (12) hours and fifteen (15) minutes.

"During the first trial the engine was operated for the ordinary requirements of the mill, which load being evidently too light for maximum economy, an effort was made to increase it for the second trial by means of a small friction brake on the line shaft, which, however, was not sufficient to furnish the additional load required.

"In the accompanying table are given the principal dimensions of the engine.

Small cylinder, diameter piston	14.	inches.
" " rod front	2.9375	"
" " " back	2.8125	"
" net area piston front	147.161	sq. in.
" " " back	147.726	"
" clearance per cent. of piston displacement	2.84	
Large cylinder, diameter piston	26.	inches.
" " rod front	2.8125	"
" net area piston front	524.718	sq. in.
" " " back	530.93	"
" clearance per cent. of piston displacement	4.	
Stroke	42.	inches.
Volume of first cylinder, including clearance	3.6855	cu. ft.
" second " "	13 343	"
" receiver and connections	11.1008	"
Ratio of second cylinder to first cylinder	3.6204	
Ratio of receiver to first cylinder	3.01202	
" " second cylinder	0.832	
Volume of steam exhausted at terminal pressure, per revolution	26.521	cu. ft.
Volume of steam retained at counter pressure, per revolution	2.3054	"

"Steam was furnished by a Babcock & Wilcox boiler. The water supplied to the boiler was drawn from the overflow of the condenser and measured in two small tanks, the delivery of which was connected with the boiler feed pump. The tanks were filled to an overflow pipe and drawn down to the lower edge of the outlet pipe.

"The capacity of the tanks was determined by filling and weighing at an observed temperature; from which the weights of water at temperatures of overflow were estimated. All water delivered by the tanks was pumped into the boiler, except as otherwise noted.

"Calorimeter observations of the quality of steam were frequently made during each trial. The weighing scale used for the first trial was not very sensitive, and the first set of calorimeter data is rejected as unreliable.

"Observations were made regularly every fifteen (15) minutes of the boiler gauge, receiver gauge, vacuum gauge, temperature of feed-water; hourly observations were made of the counter, and bi-hourly observations were made of the temperature of injection. Indicator diagrams from both ends of both cylinders were taken quarter-hourly.

"In the following table are given all the material data from the trials.

	Date of Trial.	
	April 26.	April 29.
Duration of trial ... hours.	20.	12.25
Average boiler pressure ... pounds.	78.49	92.99
" receiver pressure ... "	4.2266	8.702
" vacuum ... inches.	26.503	26.688
" " ... pounds.	13.0108	13.1016
" barometer ... inches.	29.5675	29.66
" " ... pounds.	14.5152	14.5606
" temperature of injection ... degrees, Fahrenheit.	53.10	54.583
" " " overflow ... " "	92.256	95.245
" " " air ... " "	72.150	71.250
Revolutions during trial	91424.	55856
" per minute	76.187	75.9946
Piston speed " ... feet.	533.309	531.9946

	Date of Trial.	
	April 26.	April 29.
From the Diagrams.		
Initial pressure, first cylinder..............above atmosphere.	76.638	90.698
Counter pressure "	3.9474	8.7135
Mean effective " .... front.	27.59	25.315
" " .... back.	27.618	28.2048
Initial pressure, second cylinder..............................	0.05312	7.5232
Terminal pressure, " .... absolute.	4.7339	4.709
Counter " " .... "	3.1902	2.9416
Vacuum realized "	11.325	11.619
Mean effective " .... front.	5.388	6.617
" " .... back.	4.88375	6.7933
Indicated Power.		
First cylineer.................................... front.	32.808	30.0266
" .... back.	32.967	33.5828
Second cylinder.................................. front.	22.845	27.9849
" .... back.	20.952	29.0706
Total indicated horse-power..................................	109.573	120.665
Expansions.		
Cut-off, including clearance, first cylinder....................	0.2176	0.19767
Expansion by volumes..	21.3231	23.3746
" " pressures..	19.2554	22.3526
Frictional Resistances.		
Between boiler and first cylinder............................	1.852	2.292
" first cylinder and second cylinder....................	3.894	1.190
" condenser and second cylinder......................	1 6858	1.4826
Economy.		
Total water pumped into boiler........................pounds.	38623.778	25869.98
Leakage caught from safety-valve.................. "	32.	50.
Leakage by break of water-gauge.................. "		221.182
" caught from feed pump.................. "		5.
Consumed by calorimeter.......................... "	245.	134.25
Percentage of water entrained..................................	6.3043	6.3043
Weight " " ....pounds.	2417.433	1605.046
Net steam to engine.................................. "	35928.345	23854.502
" " ....pounds per hour.	1796.417	1947.306
Steam per indicated horse-power............ " "	16.395	16.138
Calculated Economy.		
Coal per indicated horse-power evaporation, 9 to 1...........	1.8217	1.7931
Steam per hour accounted for by the diagrams................	1480.449	1482.702
Percentage of steam accounted for..............................	82.4112	76.1412
Steam per indicated horse-power per hour by the diagrams ...	13.5113	12.2877
Performance of Boiler.		
Coal burned during trial..	6640.	3862.5
Apparent evaporation per pound of coal.........................	5.8167	6.6977
Actual evaporation per pound of coal...........................	5.45	6.2754
Temperature of feed-water......................................	119.772	95.245
Steam per pound of coal from and at 212° Fahrenheit.........	6.1647	7.2779
Ash and clinker weighed back	1072.5	446.
Percentage of combustible......................................	83.8479	88.4533
" " ash and clinker....................................	16.1521	11.5467

"The economy of engine does not vary greatly between the two trials, the second trial developing the better results."

In view of the low percentage of steam accounted for by the diagrams, in both trials, the writer is inclined to think there were some serious leaks, either through the engine or in the boiler, unknown at the time of trial. Allowing a fair loss unaccounted for between the boiler and the engine, the consumption of steam per indicated horse-power per hour should have been for the first trial 15.01 pounds, and for the second trial 13.655 pounds.

Setting aside the theoretical deductions for economy which are open to criticism, the fact remains that with the unusually high expansions employed in these trials the economy shows no improvement upon that of the single-cylinder engine (operating with one-third the grade of expansion), the performance of which is detailed in the following extract from the writer's report to the proprietors of the mill in which it was running:

"The engine, 24″ diameter of cylinder and 60″ stroke of piston, is condensing and fitted with the ordinary jet condenser and reciprocating air pump.

"The injection water is obtained by a lift of 15′ from the Mississippi river, upon the bank of which the mill stands; and during the trial the condensing water entered the injection pipe, at a temperature near the freezing point. The steam valves were formerly closed by the usual weights; but previous to the trial, vaccuum dash pots were added to insure a prompt closing of the valve when liberated from the hook. The engine is furnished with a pulley fly-wheel 20′ diameter and 32″ face; driving back to the line shaft with a 30″ double leather belt.

"The exhaust of engine is closely connected to the condenser by a 10″ pipe, and steam is conveyed from the boiler by a 7″ pipe.

"The feed-water is taken from a drop leg in the overflow pipe from the condenser, and conducted to the suction of a single-acting plunger pump driven from the engine by belt.

"The entire net power of engine is expended in driving the machinery of the mill, which consists of twelve run of 54″ buhrs and three run of 48″ buhrs; two crushing rolls, each with three 12″×30″ cylinders; five rolls, each with two 12″×30″ cylinders, and one roll with two 12″×18″ cylinders.

"The bolting machinery consists of one chest with two reels; two chests with three reels; one chest with six reels, and one chest with eight reels; in all twenty-two bolting reels and forty-eight conveyors.

"The cleaning machinery consists of two 'cockle' machines; one 'scouring' machine; one 'separator,' and two brushing machines. Of the purifying machines there are seventeen, and one shaking machine; four flour packers; four stand of wheat elevators; four stand of flour elevators, and twenty-one middlings elevators. One small and two large exhaust fans.

"To this should be added the machinery of the grain elevator, which is driven by belt from the third story of the mill, and the line shafting, connecting belts, pulleys and gearing forming the general machinery of the mill.

"In the following table are given the principal measured and calculated dimensions of engine.

"The clearance was not measured, but estimated at three per cent. of piston displacement, this being the usual clearance in Harris-Corliss engines of like dimensions.

"The valve functions have been measured on the diagrams.

"The volume of steam accounted for to release is obtained by taking the mean area (feet) of piston into the piston travel (feet) per hour to point of release, to which is added the hourly volume of clearance. The volume of steam retained by exhaust closure is obtained by taking the mean area of piston, in feet, into the travel of piston, in feet, per hour, from exhaust closure to end of stroke, to which is added the hourly volume of clearance.

"The trial of engine for economy of performance was made March 13; all preparations having been completed, the trial began at 9.15 A. M., and terminated at 7.15 P. M.; duration, 10 hours.

"The load was that usually carried in the daily operation of the mill, and was held quite uniform during the ten hours' run. It is possible that the mean power developed was slightly greater than usual, from the fact that the operatives were cautioned to avoid breaks in the load, and that they obeyed the injunction is best attested by the indicator diagrams, which exhibit but slight variations in the mean effective pressure during the economy trial.

"The diagrams were taken by independent indicators, one to each end of cylinder. Forty-pound springs were used, and the drums were moved by well-constructed bell cranks, and reciprocating connections hung on a stout gallows frame. The joints of the levers and connections were carefully made, and means were provided to take up wear, and avoid lost motion.

DIMENSIONS OF ENGINE.

Diameter of cylinder	24 inches.
Stroke of piston	60 "
Revolutions per minute during trial	59.616
Piston speed " "	596.166 feet.
Factor of horse-power due area and velocity of piston	8.204
Piston stroke to release in parts of stroke	99.370
Piston stroke to exhaust closure in parts of stroke	6.067
Clearance (estimated) in parts of stroke	3.000
Volume of steam to release per hour	115038.04 cubic feet.
" " retained by cushion per hour	10189.02 "
Diameter of air pump	12 inches.
Stroke " "	15 "
Diameter of driving pulley	20 feet.
Face " "	32 inches.
Weight " "	40,000 pounds.

"The strings on the indicator barrels were only long enough to couple with the pins on the short-stroke reciprocating bar, and the recoil springs were adjusted as nearly as possible to the same tension. The length of diagrams was uniformly 4.78″.

"During the trial a pair of diagrams were taken regularly every fifteen minutes, making eighty-two diagrams, from which has been obtained the initial pressure in cylinder, piston stroke to cut off, ratios of expansion by pressures and by volumes, terminal pressure, counter pressure at mid stroke, utilization of vacuum and mean effective pressure on the piston, from which is obtained the mean power developed.

"The vacuum in the condenser and the pressure in the boilers were taken from gauges in the engine-room regularly every fifteen minutes.

"The temperature of water to the condenser was taken in the river at the mouth of the injection pipe. The temperature of overflow from the condenser was taken in the measuring tank. The temperature of feed to the boiler was taken in the feed pipe near the check valves.

"The water to the boilers was measured in the following manner:

"Two oil barrels were carefully washed inside and placed on the same level in the engine-room; to the bottoms of these was connected, by branch pipes, the suction pipe of pump; each branch being provided with an open-way cock to shut off the flow when the level had been reduced to the lowest gauge point.

"The pipe from the hot well to the pump was cut and carried out over the barrels; a connection made by branches to each barrel, and a stop valve in each branch regulated the flow of water into the tanks. The tanks, or barrels, were numbered 'one' and 'two,' and were alternately filled to the overflow notch in the rim, and emptied to the center of the branch pipe in the side of barrel, and the contents discharged into the pipe leading to the pump.

"Whilst the number one barrel was running out, the number two barrel was filling with water from the hot well, and directly the first barrel was emptied to the lower gauge point, it was turned off, and the second barrel turned on, and so on during the entire trial; the empty barrel being shut off before the full one was turned on, to prevent transfer of water from the full to the empty barrel. Directly each barrel of water was turned on, the time was entered in the log, and a tally made by the assistant in charge of the tanks. From time to time the writer's record of tanks discharged was compared with the assistant's tally to avoid error in the count.

"After the trial the capacity of each tank was determined by filling to the overflow notch, noting temperature, drawing off to the lower gauge point and weighing.

"The temperatures of the tanks of water discharged into the suction pipe of feed pump having been regularly noted during the trial, the weight of water delivered to the boiler was deduced from the number of tanks discharged, into the weight of tanks at mean observed temperature.

"The calorimeter tests of water entrained were made by drawing off from the steam drum, near the pipe to the engine, a given weight of evaporation, and condensing it in a given weight of water, noting the temperature of water before and after the steam was turned in, and the pressure of evaporation each time an observation was made.

"Twenty calorimeter observations were made during the ten hours' trial.

"The revolutions of the engine are nominally 60 per minute; but from the ten hours' continuous record by counter, the mean revolutions per minute were 59.616.

"In the following tables are given the observed and calculated data, illustrating the performance of engine and boilers. All data from the diagrams are means of eighty-two readings, and all other data are means of forty-one readings.

"The economy of engine by steam and by coal is developed from the mean quantities charged per hour."

Data from Trial of Engine.

Date of trial	March 13, 1879.	
Duration of trial	10 hours.	
Mean pressure by boiler gauge above atmosphere	92 876	pounds.
" initial pressure above atmosphere	89.376	"
" terminal pressure, absolute	12.018	"
" counter " "	2.696	"
" cut off in parts of stroke, apparent	15.560	"
" " " " aetual	18.019	"
" vacuum by gauge	26.40	inches.
" " diagrams	24.05	"
" temperature of injection	33.840°	
" " " hot well	92.725°	
" effeetive pressure	32.9792	pounds.
Indicated horse-power	270.5796	
Ratio of expansion by volumes	5.549	
" " pressures	8.643	

Economy of Engine.

Total water per hour to boilers	5037.128	pounds
Water (steam) per hour to calorimeter	10.000	"
" entrained per hour in the steam	655.583	"
Net steam per hour to engine	4371 545	"
Steam per indieated horse-power, actual	16.156	"
" " " by the diagrams	13.035	"
Pereentage of steam aecounted for	80.682	
Coal burned per hour	535.0	"
Coal per indieated horse-power per hour	1.9772	"
" " " evaporation 9 to 1	1.7950	"
Combustible per indicated horse-power, per hour	1 8328	"

Performance of Boilers.

Pressure by gauge	92.876	pounds.
Temperature of feed to boilers	114.324	"
Total steam furnished	43903.58	"
" coal fired	5350.	"
" non-combustible weighed baek	390.	"
Steam per pound of coal	8.206	"
" " " from temperature of 212° Fahrenheit and pressure of atmosphere	9.639	"
Percentage of ash in eoal	7.3	"

In both of these trials unusual care was exercised in measuring the consumption of steam, the quality of the steam and the power developed, and conditions considered, they can fairly be compared for economy of performance.

Neither engine was jacketed.

Comparing the initial pressures, expansions and economy, we have the table of results as on next page.

The initial pressure for second trial of compound tandem engine and for single-cylinder engine were substantially alike, but the expansions by pressures varied nearly as 3 to 1, and yet the difference in economy in favor of the tandem com-

Engine.	Initial pressure.		Expansions by pressure.	Steam per I. H. P. per hour.
	Above atmos.	Absolute.		
Compound Tandem, first trial........	76.638	91.153	19.255	16.395
" " second trial......	90.698	106.258	22.352	16.138
Single Cylinder.....................	89.376	104.876	8.643	16.156

pound is so small as to come within the ordinary error of observation in reading indicator diagrams for power.

The piston speeds varied as 532 for the compound tandem to 596 for the single-cylinder engine, and this is calculated to fortify the writer's opinion, that single-cylinder engines at high piston speeds and moderate expansions will equal, and often surpass, the economy of compound engines, with high expansions and the piston speed usually employed in this type of engine.

If the economy of the single-cylinder engine upon a boiler performance of ten pounds of steam per pound of coal is developed as "duty" for a pumping engine it becomes $\frac{198,000,000}{1.6156} = 122,555,000$. foot-pounds per hundred pounds of coal. And this is accomplished with 8.6 expansions of the steam; to obtain this same duty with a compound engine at a piston speed of 250 feet per minute, at least eighteen expansions would be required.

A high grade of expansion means larger steam cylinders and more expensive engines, or higher initial pressures and stronger boilers.

Comparing the terminal pressures, vacuums and economy of the two engines, we have the following table:

Engine.	Absolute terminal pressure.	Effective vacuum.	Steam per indicated H.P. per hour.
Compound Tandem, first trial........	4.734	23.069	16.395
" " second trial......	4.709	23.668	16.138
Single Cylinder.....................	12.018	24.05	16.156

Here it is seen that with a terminal pressure of 12 pounds and 8.6 expansions the economy is equal to 22 expansions with a terminal pressure of 4.7 pounds.

Referring to the previous table of comparison, it appears that an increase of the initial pressure from 76.6 to 90.7 pounds, and increasing the expansions from 19.2 to 22.3 made but a trifling increase (1.5 per cent.) in the economy of performance.

It is probable that had the compound tandem engine been loaded in the second trial to produce about 9 expansions and a terminal pressure of nearly 12 pounds, the economy would have been quite as good, and the effective work of the engine increased over 150 per cent.

American Hardware Abroad.—There is not a corner of Europe where American small cast hardware is not on sale. The tool-makers and machinists of Europe—such as Krupp, of Germany; Whitworth and Armstrong, of England, and Hotchkiss, of France, with their vast resources—are unable to produce a Moncky or screw-bar wrench equal to the American wrenches; and consequently they have to import these tools from the States. It is stated that there are no less than 80,000 dozen of them exported to Europe alone every year. It is interesting to note that Charles Moncky, the inventor of this screw-bar wrench, received only $2,000 for his patent, and is now living at Williamsburg, Brooklyn, in a small cottage bought from the proceeds of his sale. In the matter of the common pocket boxwood rules also, the American manufacturers far excel all others.

THE ACTION OF CERTAIN ADMIXTURES UPON PORTLAND CEMENT.

By Professor L. TETMAJER, of Zurich.

Translated from Schweizerischer Bauzeitung, for Abstracts of the Institution of Civil Engineers.

After acknowledging the services rendered by the German cement-makers in the position they have taken up with respect to adulteration, and the value of the investigations of Professor R. Fresenius, of Wiesbaden, the author points out that his own experiments concerning the action of certain admixtures upon cement do not coincide with the results obtained by Mr. R. Dyckerhoff. He states that his researches were undertaken with a view of learning something concerning the subject, and not in order to prove any particular theory. The influence of foreign ingredients upon Portland cement depends upon two sets of operations, which must be kept distinct; the one set being wholly of a physico-mechanical nature, the other involving a chemical rearrangement of the molecules. Both actions may result in an increase in the normal tensile strength of the mortar. The increase of strength in the mortar tests, due to the admixture of various inert, and for the most part, specifically lighter substances, as for instance, finely ground limestone, rests solely upon a reduction of the injurious effects of the volumetric increase, which freshly-ground cements always undergo in a greater or less degree. Possibly, moreover, in the case of certain cements an increase is caused by this means in the superficial area of the binding agent (*Kittsubstanz*), and therefore, an increase also in the density. It can be proved by means of the addition of slaked lime, or lime putty, to cement that the eventual augmentation of the tensile strength in the sand test thereby obtained is in no way caused by a chemical molecular change, due to the addition of such inert substances.

But the facts are wholly different when the Portland cement is mixed with certain finely ground ingredients, containing silicic acid in a state adapted for chemical combination.

Under such conditions a chemical action is set up, whereby, not only the tensile strength of the pure cement mortar, but also that of the equivalent mixture of cement with lime is frequently increased in a surprising degree. From the results obtained by former experimenters there is little room for doubt that when an improvement in Portland cement is brought about by the addition of soluble silica, this can only be attributed to the formation, in the first instance, of colloidal hydro-silicates of lime, the cement itself furnishing the lime needed for the formation of hydro-silicates. It is now pretty generally admitted that Portland cement liberates lime during the first stages of its induration. In proof of this the author states that he has found on large cubes of concrete, made of highly calcined Portland cement, having a specific gravity of 3.1 to 3 2, an efflorescent growth of carbonate of lime, and in the case of a bridge of Portland cement concrete, made for exhibition, by Mr. R. Vigier, while on the abutments, consisting of a mixture of river sand, screened ballast and Portland, there were abundant evidences of the formation of carbonates on the arch, which was composed of a mixture of Portland cement and granulated blast-furnace slag, no signs of the formation of stalagmites, or carbonates could be observed. This later fact is further important as indicating the influence of slag upon cement in works on a large scale. Free lime in the Portland cement, and silicic acid, in a state free to combine, in the added materials, are the essentials and the deciding conditions in the much-talked-of adulteration question.

Guided by his experiments, the author maintains that when, on the addition of foreign ingredients, no diminution takes place in the tensile strength of the briquettes of the mixed material, as compared with those made from the pure cement, with and without the addition of lime, the cement has been improved by such addition. There can, of course, be no question that such improvement has been effected when the tensile strength of the mixed cement, alone and with lime, is increased to a marked extent.

The action of foreign ingredients upon Portland was examined by the author, with four different substances and five varieties of cement, which were tested at various ages. The tests included, also, an investigation concerning the influence of the use of more or less water, and greater or less ramming into the molds. The substances employed for admixture were, first, pure blast-furnace slag; second, a composite slag; third and fourth, mixtures specially rich in active silicic acid. Trials were first made of the tensile strength of the slags, granulated, and not granulated, mixed only with lime, in order to study the power they possessed of forming silicates, and indurating in the manner of hydraulic limes. In some cases a tensile strength of 23.5 kilograms per square centimer was thus reached in 28 days. Analyses of the slags and cements are given, and a tabulated statement of breaking weights of a series of mixtures and pure cements follows; a large proportion of samples, in which 85 parts of cement, 15 parts of slag, and 300 parts of sand were tested, show a tensile strength considerably in excess of that attained by a mixture of one hundred parts of the pure cement with three hundred parts of sand.

ELECTRICAL TRAMWAY TRACTION.

From "Iron."

The great expense and inconvenience attending the working of tramways by means of horse-power, has led to numerous devices for effecting that object by mechanical means. Tramway traction has, in fact, long formed an attractive subject for the exercise of inventive talent in almost every direction, including, of late years, electricity. The application of this subtle power to the propulsion of carriages, and even railway trains, by no means dates from the recent practical introduction of electricity, inasmuch as, years ago, designs for electrically-driven locomotives for railway work were brought under our notice, although we need hardly say that the locomotives themselves never came into existence. Even in the present comparatively advanced stage of electrical science, invention has not yet reached that point, although by the light of what we have recently witnessed, there is no knowing how soon it may be reached. The stepping-stone, however, must be the tramways, inasmuch as they offer every facility for conducting experimental investigation and practical trials in the present connection. To tramways, therefore, inventors have naturally turned, and our columns in the near past bear witness to several attempts which have been made to solve the question of electrical tramway traction. But in the examples which have hitherto come under our notice, the car has carried a series of secondary cells, and a stationary electrical motor, which has had to drive the car through belting. A decided departure from the practice hitherto followed in this connection has been introduced in an electrical locomotive which we recently inspected. In this locomotive, which has been built for the North Metropolitan Tramway Company, instead of the electro-motor being a fixture, and having motion transmitted from it through belt gearing to the wheels of the car, the motor itself revolves, the motion being transmitted through bevel gearing. The system is the invention of Mr. C. P. Elieson, and the locomotive has been built by the Electric Locomotive and Power Company, of 6 Great Winchester Street, London. The locomotive is similar in appearance to a short tramcar, and carries a secondary battery consisting of 50 E.P.S. cells. This battery is connected up with the electro-motor, the armature spindle of which projects horizontally about 2 feet, and carries at its end a spur wheel, which gears into a fixed circular rack corresponding to a crown wheel. Thus, when the motor is started, it is, by means of this gearing, rotated, and weighing, as it does, about 7 cwt., it acts as a fly-wheel. A vertical shaft is attached to the under side of the motor, carrying at its lower end a bevel wheel, which gears into one or other of two similar wheels on the driving axle of the engine. This miter gearing is fitted with a friction clutch, by means of which the locomotive can be run either backwards or forwards. The machinery is so arranged that in no case can a speed of 8 miles an hour be exceeded, the ordinary running speed being six miles.

With regard to the store of power carried, it is to be observed that the 50 E. P.S. cells are equal to 280 amperes, and the average consumption is put at 45 amperes per hour. It therefore follows that we have a good six hours' supply of running power in each engine. Both the locomotive and the tramcar can be electrically lighted at night by means of glow lamps worked from the battery without materially shortening the duration of the supply. We recently inspected this locomotive and its working at the tramway company's depot, at Stratford. The limited space afforded by the depot allowed no opportunity for anything like a practical run to be made. The engine, however, alternately drew and pushed one of the company's ordinary tramcars up and down a line of rails with satisfactory results. The operations of starting, stopping and reversing were effectively performed, the mechanism answering readily to the lever. The machinery, in fact, is very simple, and can easily be adapted to the tramcar itself, if it should be preferred, in building new stock; but the object is, of course, to utilize the old stock, and hence, for the present, at any rate, the engine will be a separate vehicle. The arrangements at Stratford for charging the batteries are in keeping with the locomotive as regards simplicity. There is one of Marshall's 12-horse, double-cylinder portable engines, which drives a dynamo, from which the current is led to the locomotive, the latter being run in from the road and placed on a convenient siding. Or even this may be avoided by leading the electric conductor to the road and connecting it up to the locomotive whilst standing there. With regard to the cost, we have no absolute figures to go by, and indeed we could hardly expect them yet. It is, however, stated that the cost of an installation of a charging station and locomotives to replace a given number of horses, and to do the same amount of work, is considerably less than the cost of the horses, harness, and stabling, while the cost of maintenance is put at 40 per cent. less. This is quite conceivable when placed by the side of the statement that four tramcars require forty-four horses to work them, and when it is remembered that the cost of fodder alone for the animals amounts to about £25 per week. On the whole, therefore, it will be seen that the new electrical locomotive gives promise of success; and if, in practice on the Stratford line its performances equal the expectations formed of it, we may look for its adoption there and elsewhere. We understand that the Electric Locomotive Company are negotiating with the Tramway Company to work their new system, now being laid down from Stratford Church to Ilford, entirely by these electrical engines. General Hutchinson, R. E., of the Board of Trade, has inspected the engine, and has expressed his willingness—subject to a few trifling alterations as to the brakes, &c.—to grant a certificate for the locomotive to be run on the roads. We have hinted at the possibility of railway traffic being carried on at no distant period by the means we have been describing. In support of this, we may mention that the officials of one of our railways have interested themselves in Mr. Elieson's invention, and that the Electric Locomotive Company are now building a powerful engine, with the view of demonstrating the applicability of the system to railways. But, whatever may be the result in that direction, there can be no doubt that this system of electrical haulage is specially adapted for use in crowded thoroughfares, where the transmission of electrical energy by means of suspended or channeled conductors is inadmissible.

American Tools in Competition.—American augers and auger-bits are used the world over, no other nation being able to compete.

TIDES AND COAST-WORKS.

By THOMAS STEVENSON, President of the Royal Society of Edinburgh, M. Inst. C. E.

Proceedings of the Institution of Civil Engineers.

As regards the very important but also very abstruse subject of the tides, which forms the first part of the matter which has been remitted to me by the Council, I believe it is not expected that I should enter systematically into it, the more so as there are many treatises which fully embrace all the details in so far as the extent of our knowledge and the state of mathematical science enables the investigation to be undertaken. I may refer in particular to the remarkable treatise on the Tides, in the "Encyclopædia Metropolitana," by Sir John Herschel and also to the works of Airy, Laplace, and Newton.

It seems only necessary, by way of preliminary remark, to note the confusion which has been introduced into the subject, by neglecting to take into consideration the large lapse of time, between the passage of the moon across the meridian and the time of high water, due to the inertia of the water, and the irregularities of the shores and bottom of the sea, in connection with what is called the "Establishment of Ports," or what is generally termed the times of high water on the days of full and change of the moon. As is now well known, the tides do not occur synchronously with the passage of the moon across the meridian, but lag behind for about three or four tides. Another great cause of confusion has arisen from the difference which exists between the phenomena of the flow and ebb of the currents and the vertical rise and fall of the tides; and then again there are many tides which are not directly due to the attraction of the moon, but are strictly of a derivative nature, being produced by their simply spreading from the great primary tide, round points of land and islands. Dr. Whewell did much to establish a map of cotidal lines, with the view of extricating the question from those difficulties, and clearing it from the disorder which formerly existed.

It is hardly necessary to notice that, in so far as regards the British coasts, the great tidal wave, after passing over the Atlantic Ocean, splits upon the Western coast of Ireland, and proceeds in two courses, one branch forming a wave which passes through the English Channel, and the other through the channels of the Orkney and Shetland Islands, and that these branches meet each other in the North Sea, near Yarmouth.

I need scarcely point out how large and beneficial is the influence of these tides on the commerce and wealth of the country, by enabling vessels, even of heavy draught, to pass inland from the ocean. But in so far as our subject is concerned, viz., "Lighthouses," "Coast Harbors of Refuge," and "Coast-Protection Works," we have, principally, to consider in what way the tidal current influences such works.

All sea-works are affected beneficially or the reverse by the height to which the tide rises, in consequence of the configuration of the land, and on the velocity, due to the same cause, which the tidal currents assume. So long as the tidal wave is passing through great depths in the ocean, the tidal range is comparatively small, but when it enters a bay or firth, and especially a tidal river having converging shores, very great changes are produced, as in the case of the Wye, at Chepstow, where the tide has been known to rise 56 feet. This, viewed as a mechanical question, may be accounted for, as stated by Dr. Whewell, on "the principle of the conservation of force. When any quantity of matter is in motion, its motion is capable of carrying every particle of the mass to the height from which it must have fallen to acquire its velocity; but if the motion be employed in raising a smaller quantity of matter, it is capable of raising it to a height proportionally greater. In bays and channels which narrow considerably, the quantity of water raised in the narrow part is less than in the wider, and thus the rise in such cases is greater." A familiar illustration of this principle is the simple experiment of plunging a funnel with its wide mouth downwards into a vessel of water, when a jet of water springs out of the narrow end of the funnel to a height considerably above the level of the water in the vessel.

As regards the influence of the tides upon wind-waves, it is obvious that the effect of currents running in opposite directions to waves, whether they are merely of an oscillatory nature, or those greater waves of translation which affect the bottom at greater depths, must necessarily result in violent conflict, and give rise to what are called "Races" in England, and "Roosts" in Scotland, and which may be witnessed on a small scale in all rivers where the outward current meets the sea and encounters the waves caused by on-shore winds.

In some cases this antagonistic action between the tidal current and the waves increases the height and force of the waves on sea-works and on the shore-line, while in other cases it produces the contrary effect, and acts, therefore, protectively as would an outer breakwater of masonry.

A well-developed example of the sheltering affect of the Sumburgh "Roost," near Sumburgh Head, the most southern point of the mainland of Shetland, came particularly under my notice. At one of my visits to that place, I asked the light-keeper to observe particularly during the next heavy gale, whether the waves which reached the shore while the "Roost" was in full action, were not of smaller magnitude than when the action had ceased; and some time after I received the following remarkable testimony on the subject:—

"We had a very severe gale from the southwest yesterday, and, being the first gale we have had from that quarter since you were here, I paid particular attention to the state of the sea in the West Voe through the day. By daylight in the morning it was blowing very hard, with a most terribly heavy sea rolling into the West Voe and breaking over the top of the banks, while low water lasted. But with regard to what you said to me about the tide in the 'Roost' acting as a breakwater to the Voe, your opinion is right, for, during the last hours of flood and the first two hours of ebb-tide, in particular, a small boat could have gone till within a few yards of the 'Roost,' between the Lighthouse and the Horse Island, although the sea was still in the same raging state beyond the 'Roost,' and as far as the eye could reach towards Fair Isle and away to the west."

I may remark that wherever the land projects far from the general coast line, "tidal races" will be found to exist, because the currents which oppose the passage of heavy waves are there intensified. Probably the best illustrations of tidal and wave action are to be found in the Pentland Firth, which may be regarded as the most dangerous navigation of any on the British coast, presenting as it does, so many "races" or "roosts." Some writers have alleged that these "roosts" are due to the meeting of contrary currents, while many sailors, on the other hand, believe them to be due to shoal water, produced by abrupt vertical changes in the rocky bottom. But the true cause is undoubtedly the large oceanic waves encountering a tidal current running in a direction more or less opposed to their own. For the "roosts" on the west coasts of Orkney and Pentland Firth are known to be worst with ebb-tide and westerly gales, because the Atlantic swell and the current of ebb-tide are opposed; while those again on the east coast are worst with flood-tides and southeasterly swells. The depth of water where the "Sumburgh Roost" runs is not less than 40 fathoms, showing that it is not due to shoal water or to any submerged upstanding rocks.

A further proof of the influence of the tide upon the waves is afforded by the experience derived in conducting coast-works, where it has been found that the time at which waves of abnormal height gave rise to damage, was when the tide running near the shore was at, or nearly at, its greatest velocity. Murdoch Mackenzie, the justly celebrated marine surveyor and hydrographer of last century, remarks, in speaking of the Orkney tides: "that the spring tides acquired a considerable degree of strength in less than one hour after the quiescent state; neap tides are hardly sensible in two hours after still water; the stream is most rapid commonly between the third and fourth hours of the tide."

In cases where the tide runs close to

or near the shore, many examples might be given to show that the damage to harbor and other works took place after the tide had attained its greatest velocity. It is sufficient to refer to Peterhead harbor, where, at two hours' ebb, after vessels had got aground in the basin, three abnormal waves burst over the seaward pier, knocked down the protecting sea-wall, and washed sixteen persons off the quay into the water. The volume of these waves was such as to set afloat again vessels which had already taken the ground. The contractor's agent stated that, at Alderney breakwater, "the heaviest seas and the greatest rush of water over the wall occurred an hour after high-water."

Velocities of Some of the Most Notable "Races."

Names of Places.	Authorities.	Velocity at Spring Tides in Statute Miles per Hour.
Portland Race...........................	Admiralty Channel Pilot..	5.75 to 6.9
Open Ocean between Orkney and Shetland.......	" North Sea Pilot	5.76
Hoy Sound, Orkney.......................	" " "	6.90
Holm Sound, "	" " "	6.90
Sumburgh Roost, Shetland............	" " "	8.06
Burger Roost, Orkney.........	" " "	8.06
Hell Gate, New York, east current...............	Prof. H. Mitchell........	8.50
Doris Mor, Argyllshire.........................	Captain Bedford, R. N...	9.22
Gulf of Corrie Vreckan Argyllshire.............	" " "	9.83
Roost, near Louther, Pentland Firth.............	Admiralty North Sea Pilot	10.36
" Swona, " "	" " "	10.36
" Pentland Skerries.....................	" Survey	12.20

Criteria of Exposed Coasts.—As the result of many observations, I regard the following as being descriptive of those parts of the coast which are most liable to the impact of unusually heavy waves. (1) The waves are most destructive when they come in at right angles to the shore line. (2) Their power is increased in proportion as the direction of the main body of the tide approaches to coincidence with the direction of the heaviest swell, and they are probably worst at those headlands on which the tide splits. (3) Where a considerable part of the coast retires, there will be less sea during the strength of the tide, even although the waves come in at right angles to the shore, because the tide keeps outside, following the direction of the regular trend of the coast; but this will probably not hold true of small re-entrant hollows of the shore. (4) Where the line of exposure and the tide current are parallel to the coast, if the tide runs in a line very near the shore, as is the case in short narrow channels, where the velocity of the current is increased, there may nevertheless be an unusually heavy sea.

Level Assumed by Mud as a Measure of Exposure.—In the "Proceedings of the Royal Society of Edinburgh," vol. iv., p. 200, I referred to a feature which will be found of very considerable value in judging of the exposure of a coast. This is the level below the surface of low water at which mud reposes on the bottom. Though at first sight it might appear unlikely that the disturbance of the sea level by wind-waves would be propagated to great depths, there are numerous facts which prove the contrary. Although the absence of mud in any locality proves nothing, because the tide currents may sweep it away, or the geological formation may not produce it, yet its presence seems both a delicate and certain test of the lowest limit to which the disturbance originating at the surface has reached. Thus, as the waves progressively decrease in magnitude in the North Sea between Shetland and the coasts of the Continent, the level of repose of mud progressively rises nearer to the surface, from a depth of 80 or 90 fathoms to only 8 fathoms at the mouth of the Elbe, and to 12 fathoms off the coast of Holland, where ships can take the open beach in nearly all weathers without any protective harbors. If, therefore, we find, in front of a proposed harbor or coast work,

APPROXIMATE HEIGHTS OF WAVES DUE TO LENGTHS OF MAXIMUM FETCH BY OBSERVATION AND BY FORMULAS.

Place of Observation.	Length of Fetch in Nautical Miles.	Observed Height of Wave.	Height due to Fetch calculated from Formula $h=1.5\sqrt{d}$	Height due to Fetch calculated from Formula $h=1.5\sqrt{d}+(2.5-\sqrt[4]{d})$.
		Feet.	Feet.	Feet.
Scapa Flow	1.0	4.0	1.5	3.0
Firth of Forth	1.3	1.8	1.8	3.2
Granton	2.8	4.0	2.5	3.75
Craignure, Sound of Mull	3 5	2.0	2.9	3.9
Granton	6.0	4.0	3.7	4.6
Lough Foyle	7.5	4.0	4.1	4.96
Clyde	9.0	4.0	4 5	5.25
Colonsay	9.0	5.0	4.5	5.25
Dysart	10.0	4 2	4.9	5.5
Invergordon	11.0	3.5	5.0	5.7
Lough Foyle	11.0	5.0	5.0	5.7
Glenluce Bay	13.5	5.5	5.6	6.1
Anstruther	24.0	6.5	7.5	7.7
Lake of Geneva (stated by Minard)	30.0	8.2	8 2	8.37
Buckie	31 0	7.0	8.4	8.5
"	38.0	7.0	9.2	9.2
"	38.0	8.0	9 2	9.2
"	40 0	8.0	9.55	9.5
Macduff	44.5	8.0	10.02	9.9
"	45.5	10.0	10.2	10.0
Douglas, Isle of Man	65.1	10.12	12.0	11.76
Kingstown	114.0	15.0	16.0	15.25
Sunderland, distance measured from Broken Bank	165.0	15.0	19 3	18.15
		149.82	165.57	162.68
Mean	....	6.5	7.1	7.07

that mud reposes within a few fathoms of the surface, I believe we have in that fact certain ground for concluding that our works will never be assailed by a very heavy sea.

Line of Maximum Exposure.—The effect of the action of waves against the shore must obviously vary with the line of maximum exposure, or in other words, the line of the greatest fetch or reach of open sea, which can be easily measured from a chart. The engineer has then to ask himself in what ratio, to the lengthening of this line, the height of the waves may be expectd to increase. The result of many experiments on canals and on the Firth of Forth in 1850 and 1852 was that the heights of the waves increased most nearly in the ratio of the square roots of the distances in miles from the windward shore, or when $h=$the height of the waves in feet from crest to trough, $d=$distance in miles, and a a coefficient varying with the strength of the wind.

$$h=a\sqrt{d}$$

so that the height of the waves increases in a parabolic curve as they leave the windward shore. For short reaches and very violent squalls a modification of the formula is necessary; but in all ordinary cases and ordinary gales the coefficient in the above formula may be assumed as 1.5.

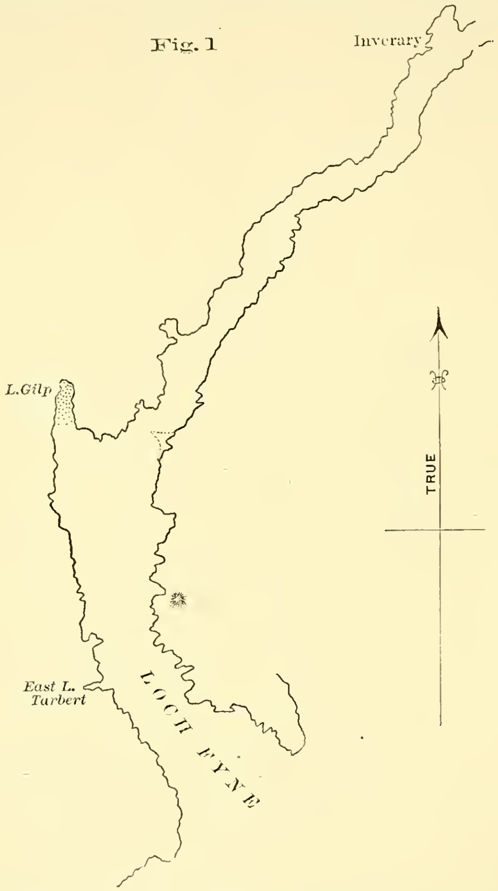
For shorter distances and violent squalls the following formula is more applicable $h=1.5\sqrt{D}+(2.5-\sqrt[4]{D})$.

It should be carefully noted, however, that there are modifying elements attending the cases of waves approaching the land obliquely; for in consequence of the reduction of the depth, they change their directions and approach the general line of the beach more nearly at right angles, and thus strike with greater force than might be expected. There are also exceptions due to geographical configuration of the land. In Loch Fyne (Fig. 1), for example, the wind and waves seem to alter their direction with the winding character of the Loch, so that the effective fetch is greater than the length of free water in the Loch would lead one to expect. In other cases the height of the waves is reduced by increased width of water as at Craignure, in Mull, shown in Fig. 2, where, during the winter of 1853–54, it was less than the formula indicates.

Another modification in the opposite direction is shown in Fig. 3, where the waves which enter a harbor-mouth at B, though apparently generated by the fetch AB, are also largely due to the fetch CB.

Reduction of Height of Waves Occasioned by Shallow Water.—Another all-important matter is the destruction of the waves, or reduction of their height, produced by the shallowing of the water near the shore. That this influence, in the case of heavy seas of the kind called waves of translation, is felt at great depths and at great distances from the coast line, is obvious from a statement by Sir George Airy, that heavy ground-swells have been known to break in a depth of 100 fathoms. The great Atlantic seas, before they break upon any but the most exposed portion of our coasts, have probably suffered a considerable diminution of bulk and decrease of velocity. So soon as the lower extremity of the undulation touches and is

Fig. 1



reduced by a reef or shoal, the upper extremity, by the process which is known as cresting, loses height in proportion. But the wave is not tripped up, and though somewhat lessened and retarded, still continues to rush onward upon the coast. The actual destruction of the wave takes place in shallower soundings. The late Mr. J. Scott Russell, who has conferred so many obligations on the maritime engineer, found that waves break when they pass into water of the same depth as their height, but there are exceptions to this law. In 1870, I noticed at Scarborough, that waves broke when the depth of water was double the height of the wave, the depth being measured below the mean level, and the height from hollow to crest.

Fig. 2

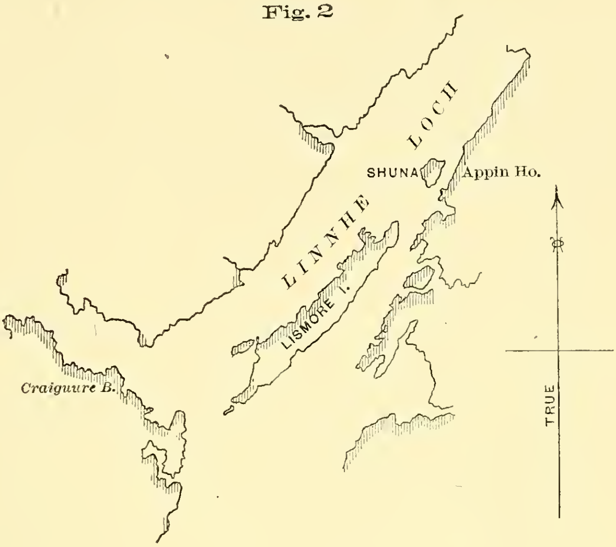
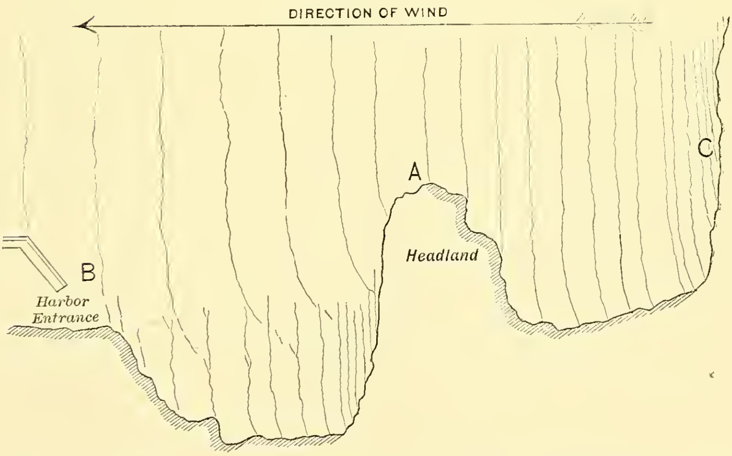


Fig. 3



Force of the Waves.—By means of a marine dynamometer, the force of the waves was ascertained at Skerryvore Lighthouse in the Atlantic, when during a heavy westerly gale I found that a force equal to nearly 3 tons per square foot was registered; while at Dunbar, where the observations were continued for a much longer period, a force of $3\frac{1}{2}$ tons was registered on more than one occasion.

Coast Works.

The most seaward and most exposed of sea works are generally lighthouses erected on outlying rocks in the sea.

As regards the design of this class of sea works, much as Smeaton's tower has been appreciated, I am distinctly of opinion that, in one very important feature, namely, the outline, the former tower by Rudyerd is decidedly superior for a small rock such as the Eddystone. It is long since I expressed that opinion, and subsequent experience has only tended to corroborate it. I have given general rules in my book on "Lighthouse Construction and Illumination," 1881, p. 28 *et seq.*, which I think will be found useful as a guide to selecting the safest modes of construction.

Fig. 4

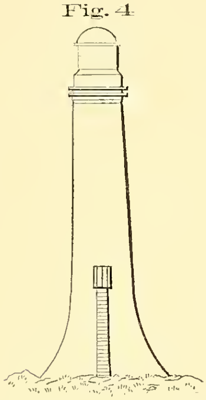


Fig. 5

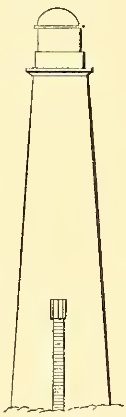
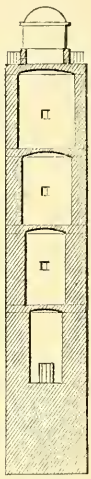


Fig. 6



The profiles shown in Figs. 4, 5 and 6 are suitable in situations where the rock is either soft, hard, or of small dimensions respectively.

Modifying Influence of the Configuration of Rocks on Breaking Waves.—I am satisfied of the great influence exerted by the shape and height of the rocks on which lighthouse towers are built; and I feel bound to take this opportunity of again expressing my conviction that Smeaton's tower should not be regarded as a safe model for imitation on rocks which are exposed to a heavy sea. Nothing less can be deduced from the remarkable fact that the level above the sea at which fourteen blocks of 2 tons each, set and fixed by joggles, dovetails, and cement, were dislodged and swept away by a summer gale at Dhu Heartach, is the same as that at which the thin crown-glass panes of Winstanley's lantern remained unbroken through the storms of a whole winter. It was on this principle, and in consequence of this experience, that a change was made in the original design of the Dhu Heartach, and the solid part carried up to the same level above high water as the lantern in Smeaton's tower.

The very remarkable cases of wave action exerted at high levels on the rocks at Whalsey, Unst, and Fastnet, are further corroborative of this view.

To decide upon the probable exposure of any rock, and the height of the dangerous impact of waves above high water, many elements have to be considered; the height of the waves, the height and configuration of the rock above and below low water, and the depth and configuration of the bottom of the sea; and it is, unfortunately necessary to add that the influence and relations of these elements have not as yet been sufficiently studied. What may be the effect, whether as shield or conductor, of a given height of rock upon a given height of wave; what may be the effect of such a deep track in the bottom of the sea as that observed by Mr. D. A. Stevenson near Dhu Heartach; or how much would depend on the direction of such a track, or on the level at which the rock is steep in relation to the height of tide most favorable to heavy seas—are all questions of great importance, still unsolved and well worthy of the attention of the engineer. A rock like Dhu Heartach certainly acts at once as a breakwater against the smaller class of waves, but a dangerous conductor to the heavier. Again, in some observations I made at Skerryvore in 1845, interesting difference were found to exist in wave-force at different levels:

WAVE-FORCES EXERTED AT DIFFERENT LEVELS ON AN EXPOSED PART OF THE SKERRYVORE ROOK.

Date.	Remarks.	No. of Dynamometer.	Pressure in lbs. per square foot.
1845.			
Jan. 7	Heavy sea	No I.	1,714
“ 7	“ “	No. II.	4,182
“ 12	Very heavy swell	No. I.	2,856
“ 12	“ “ “	No. II.	5,032
“ 16	Heavy ground swell	No. I.	2,856
“ 16	“ “ “	No II.	4,752
“ 22	A good deal of sea	No. I	2,856
“ 22	“ “ “	No. II.	5,323
“ 28	Heavy ground swell	No. I.	2,627
“ 28	“ “ “	No. II.	4,562
Feb. 5	Fresh gales	No. I.	856
“ 5	“ “	No. II	3,042
“ 21	“ “	No. I.	1,827
“ 21	“ “	No. II.	3,422
“ 24	Fresh breezes	No. I.	1,256
“ 24	“ “	No. II.	3,802
Mar. 9	Ground swell	No. I.	1,256
“ 9	Waves supposed to be about 10 feet high	No. II.	3,041
“ 11	Short sea	No. I.	1,028
“ 24	Heavy sea	No. I.	2,281
“ 24	Waves supposed to be about 20 feet high	No. II	4 562
“ 26	Swell	No. I.	1,256
“ 26	Waves about 6 feet high	No. II.	3,041
“ 29	Strong gale with heavy sea, the highest waves supposed to be 20 feet	No. I.	2,856
“ 29	and the spray rose about 70 feet	No. II.	6,083

Two dynamometers were affixed to the rock, No. I. several feet lower, and about 40 feet seaward of No. II.; and, as will be seen in the table, the force registered at No. II. was generally about twice as great as at No. I. It seems to me that it would be of great value, before designing lighthouse towers, to take what may be called dynamometric sections, such as this one taken at Skerryvore, and to examine the results in relation to the varying profile of the rock, and, if possible to different stages of the tide. Such sections it need hardly be observed, will never form a perfect guide in the particular instance, for we shall no sooner have obtained our observations than we shall begin to change the profile of the rock by the addition of the tower itself, and thus to alter the very conditions of what we have been observing. But it is only in this way that I can foresee any chance of our advancing towards sure knowledge of the general law; and I embrace this opportunity of suggesting this course of observation to the younger members of the Institution.

Harbors of Refuge.—The next class of works reckoned seawards on approaching the coast, are those large structures to which the name of Harbors of Refuge is given. They are distinguished from tidal harbors by the generally greater depth of water which they require to possess, in order to fulfill the objects for which they are designed, while the area which they enclose must also be larger. The requisites are shelter during storms, good holding-ground, and safe access at all times of the tide and in all states of the weather. A breakwater, though a passive, is yet a real agent, having work to do. Many thousand tons of water are raised and maintained above sea level by wind waves, and these waves must either be suddenly stopped, or as suddenly reversed in direction, or else more slowly destroyed within a given space. This is the work assigned to the breakwater, and there are two ways in which it can be done. One way is by means of a plumb wall, which alters the direction of the moving water by causing it to ascend vertically above the parapet of the wall, and then allowing it to fall vertically again, so that the waves are finally reflected and sent back seawards. The other method is to arrest the undulations by a long, sloping wall, so as to give room for the mass of the waves to fall down and destroy themselves upon the surface; but if the slope be not sufficiently long to enable the waves thus fully to destroy themselves, they will, though reduced in height, pursue their original direction, pass over the top of the breakwater, and thus disturb the tranquillity of the harbor. In such a case as this, therefore, the breakwater has failed to do its full share of work, and the necessary amount of shelter has not been produced.

Best Position for Harbors of Refuge.—Opinions have been recently expressed that a harbor of refuge should be placed in a re-entrant part of the coast, and never at any part which is salient. Now, it is of great importance that such a question as this should be fully discussed, as the result must materially affect the interests of commerce and shipping. Various conditions, statistical, geographical and local, should be considered in this question.

(1) *Statistical.*—So far from being necessarily placed in the neighborhood where most shipwrecks have occurred, as has been alleged, or as escape for vessels locally embayed, the harbors of refuge should, in my opinion, be situated as near as possible to the normal track of shipping. Thus, on the occurrence of a gale, a refuge will be ready in a position which can be quickly and safely approached by the greatest possible number of vessels, both large and small.

(2) *Geographical.*—The true situation for a harbor of refuge is rather upon a salient than on an embayed part of the line of coast, because (1), as I have already stated, a salient part of the coast will lie nearer to the line of the general passing trade than a re-entrant part; and (2), vessels seeking a haven and failing to make it, will not find themselves embayed, but be still well to windward, and have sea room to bear away for some more distand haven on either hand. There is, indeed, a sense in which a harbor of refuge in the bottom of a bight may be regarded as a source of danger, instead of a source of safety. Cardigan Bay, in Wales, for example, is just such a place as might, perhaps, be selected. But though a harbor in Cardigan Bay might, in certain exceptional cases, do good, it would be dearly purchased if the presence of the harbor tempted masters to leave the track of safety and unnecessarily to embay themselves. It will, I think, be generally admitted that if, from fog or snow showers coming on, a vessel failed to pick up the position of the harbor in the bay, there would be hardly a chance of her escaping shipwreck. A harbor of refuge on the principle asserted is either kill or cure, for it offers but one chance to the distressed vessel, which she must seek at the cost of embayment; but a harbor of refuge on a salient part of the coast offers a chance of shelter without necessarily compromising the safety of the ship in case she fails to make it.

(3) *The Local Conditions Pointing to the Proper Situation for a Harbor of Refuge are:* (1) The inclosure of the greatest area of sufficiently deep water for the least extent of breakwater to be constructed. (2) The quality of the holding-ground in the anchorage thus to be sheltered. (3) The proximity of suitable material for the construction of the breakwater.

Best Mode of Construction of a Harbor of Refuge.—With reference to the best mode of construction for a harbor of refuge in an exposed situation, there will always be considerable differences of opinion among members of the profession. I shall simply state the form of construction which, on the whole, I consider to be best in situations where the place is fully exposed to the heaviest class of waves.

A very obvious and very important point regarding the stability of such a structure as a breakwater has reference to the depth below low water, at which the waves cease to exert any considerable impact upon the materials on which the superstructure rests. Information of great importance was derived from the history of the Wick breakwater, for which my firm were engineers, and which, so far as I have been able to ascertain, was subjected to the heaviest waves that ever assailed masonry. It is sufficient to state that the results which I have obtained, at many different parts of the coast by means of the marine dynamometer already referred to, have been far exceeded by the effects produced by the very anomalous waves which assailed the harbor works of Wick, where the contractor's staging, though consisting of greenheart timber, was found quite unequal to resist the stroke of the sea, and where the heavy rubble which formed the substratum of the work was moved at a depth of about 18 feet below low water. In 1872, a huge monolithic block of concrete, weighing, in all, 1,350 tons, was removed bodily out of its position, and carried to the lee of the breakwater. Extraordinary as this may appear, it was surpassed in 1873, when another concrete mass which had been substituted for the one that was moved, was in like manner carried away, though it contained 1,500 cubic yards of cement and rubble, the weight of which was about 2,600 tons. Yet it is remarkable that after the last damage which took place to the breakwater, when we thought of removing the foundation courses, which were set on edge, we found it impossible to do so, owing to their being so firmly embedded in the rubble base; no part of the foundation of the breakwater was ever moved, nor any of the rubble base ever disturbed, at a lower level than 18 feet under the water. *I am, therefore, of opinion that a level of from* 18 *to* 20 *feet below low-water level may be safely assumed as that of practical stability.* In Fig. 7, showing a section of the end of Wick breakwater, it will be noticed that the bay consists of a sandy bottom, and it is, as I have said fully exposed to the swell of the North Sea. I conceive that the safest and most economic profile of construction, would be as shown in Fig. 8, a mass consisting of rubble extending from the bottom to within 20 feet of low water; when the base had been brought up to this level, blocks of concrete, weighing

Fig. 7

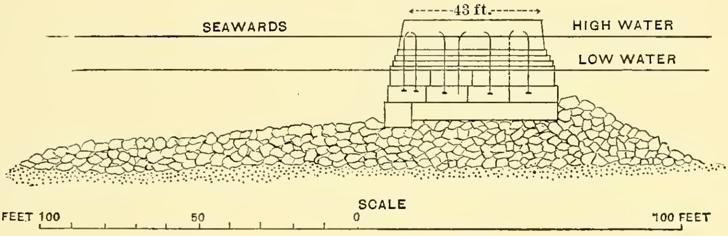
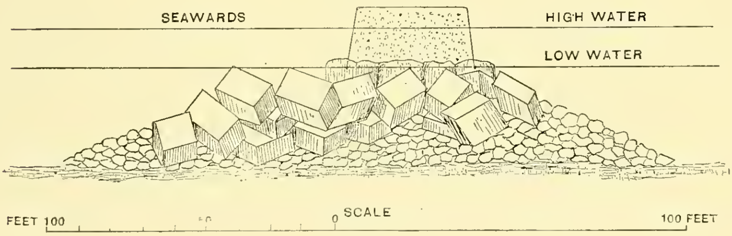


Fig. 8



from 100 to 200 tons, should be deposited on the top and outer or seaward surface of the rubble base, till they come above low-water level. Betwixt the spaces at the top of these blocks bags of concrete should be placed, so as to form a level platform above low-water level. upon this a solid mass of continuously-built concrete should extend from end to end of the breakwater, which should be not less than 10 feet above high water, and about 45 feet in breadth. I hold that a structure designed on these principles would resist the force of the sea in any situation, provided the sea slope were of sufficient extent. This was the design proposed for the Peterhead Refuge Harbor, and which was approved of by the Committee on Convict Labor.

Mattress Breakwaters, or Training Walls Constructed of Fascines.—There are in many parts of the world bays and arms of the sea of so shoal a character as to cause the waves to break several miles off the shore, but where difficulties of another kind arise from the soft nature of the subsoil; so that although there is no very violent sea to be encountered, yet breakwaters of concrete or masonry are unsuitable, owing to this softness of the bottom, for the waves, reduced though they be, are still able to produce sufficient reaction from the outer face of the breakwaters to plough up the bottom. In order to meet these difficulties, structures called mattresses, which possess peculiar characteristics have been resorted to in various parts of the world, particularly in Holland and America, where they have been found very suitable. In the well-known case of the River Mississippi, for example, Mr. Eads most successfully removed the bar by means of mattresses. The requisites for such structures are that they should be of small specific gravity and of open texture. They must also project but little above the bottom, so as to avoid coming within the direct influence of the breaking action of the waves, and thus to cause reaction, which would endanger the foundations. They must, in short, operate strictly as submarine breakwaters in stopping the action of the waves at the bottom, while they also possess a certain amount of pliancy to enable them to adapt themselves to considerable variations in the level of the bottom, so as to deflect the underwater currents.

Commercial Harbors.—It would far exceed the limits of this lecture were I to attempt to take up the subject of commercial harbors and the like. It may, however, be right to define the great object which must be kept in view in carrying out works of that nature, and that object is to produce a harbor which may easily be taken in rough and stormy weather, without endangering the tranquillity of the internal area; for it is the combination of an easy and safe entrance and exit, with what sailors call a good "loose," and a smooth interior, which alone constitutes a good harbor.

It must further be remembered that a bad result may ensue from devoting an exclusive or too great an amount of attention to one branch of the subject, however desirable the securing of that branch may be in itself; such, for example, as obtaining deep water at the expense of still more important conditions, viz., suitable protecting works and sufficient internal area. The disregard of a due proportion between the internal area and the depth of a harbor has in many instances produced harbors which cannot be said to deserve that name. In order to show how the tranquillity of a harbor may be affected, and how cautious therefore the engineer should be in changing the existing physical relation, I have thought it right to refer to some of the many works which may prove injurious.

Causes of Insufficient Reduction of Height of Waves.—The causes of insufficient reduction of height of waves after entering a sheltered basin may be stated to be too little breadth in relation to width of entrance, or adequate area in relation to the magnitude of the waves outside, also the surrounding of the internal area with vertical walls, and the absence of sufficient length of spending beach to destroy the waves and prevent recoil.

A formula for calculating the reductive power of harbors will be found in my book on harbor construction.

Commercial Value of Depth of Water.—I may state that I have found that the commercial value of harbors or rivers increases as the cubes of the depth of water, although no stated rule can be regarded as more than generally true. The following formula is designed to apply to this subject when d represents the draught of a vessel in feet; t, the burden in tons; a, a constant depending on build,

$$t=\frac{d^3}{a} \text{ and } d=\sqrt[3]{a\times t}$$

Coast Protection Works.—The last branch of the subject which has been assigned me refers to works which are furthest from the action of the sea, or those for the protection of the land itself.

The physical configuration of the coast-line affords, as everyone knows, a series of the most varied vertical and horizontal profiles. It is generally owing to the effects of atmospheric action, combined with wave action, that such phenomena are due. The two parts of the British coast which best illustrate the particular case of moving of sand and shingle are those of the English Channel and the Moray Firth. I have always been of opinion, I may remark in passing, that the action of tidal currents has nothing to do with the throwing up of shingle on any coast, and the valuable paper of Sir John Coode should, I think, set this matter fully at rest. The breaking of waves at right angles to the coast is quite sufficient to account for the heaping up of shingle between high and low water mark, while the oblique action of the waves sufficiently accounts for the traveling movement of the shingle in the same direction as the heaviest winds. But the cause of the formation of bays or creeks must generally be sought for in the unequal hardness of the different members of the geological formation which confront the sea, and which form a remarkable contrast to the rocky strata or igneous class of rocks which continue to maintain their integrity, from their greater hardness.

The general slope of a fragmentary beach must depend upon the size and nature of the particles and the force of the sea. The great object, therefore, in artificial works of protection is to design the profile of the wall so as to alter as little as possible the symmetry of the beach. Where isolated rocks or large boulders are left projecting above the surface of a sandy shore, there will generally be found around them hollows corresponding in depth and form to the kind of obstruction which the rocks present. The principal point in the design of artificial works of protection is, therefore, to avoid great and sudden obstructions to the movement of the water. The best form that could be adopted in any situation would, of course, be the contour of the beach itself; but this would answer no possible purpose; and as the wall is to consist of heavy blocks of stone instead of minute particles of sand, it is clear that a much steeper slope may be adopted than that which we may call the profile of conservancy of the shore, provided the lower part of the slope be flattened out so as to meet the sand at a low angle. The action of a bulwark is to arrest the waves before they reach the general high-water mark, and to change the horizontal motion of the fluid particles to a vertical plane, or to compel the waves to destroy themselves on an artificial beach consisting of heavy stones. To prevent underwashing, the two following requisites should therefore as far as possible be secured: First, the foundation courses of the wall should rise at a very small angle with the beach, so that their top surfaces may form a continuous curve with the profile of conservation of that portion of the beach out of which the wall springs. Secondly, the outline of the wall should be such as to allow the wave to pass onwards without any sudden check till it has reached the strongest part of the wall, which should be placed as far from the foundation as possible.

Loose Rubble a Good Protection for the Foundation of Bulwarks for Protecting Land from the Sea.—Loose blocks of angular rubble furnish in most cases the best possible security when the soil is soft or friable, for the waves are swallowed up by the interstices. A regular sloping sea-wall or bulwark with a smooth surface becomes, when the soil is soft, a double-edged sword in working its own destruction at top and bottom; for it transfers the duty of destroying the waves from the masonry to the unprotected soil at the top, and to the loose sand or gravel at the bottom of the wall. While the foundations are underwashed by the reaction upon the soft bottom, the upper parts of the masonry are deprived of support by the falling water and spray, which are led up by the masonry, and soon wash away the soil at the top.

Vertical Walls.—For the reasons which have been stated, it is plain that a vertical wall is in most cases unsuitable for a sandy beach. Instead of altering the direction of the wave at a distance from its foundation, the whole change is produced at that very point; and unless the wall be founded at a considerable depth, its destruction is all but certain. Where the materials are costly, but admit of being easily dressed, I am disposed to think that a horizontal, or nearly horizontal, apron or platform of timber or masonry, connected with a vertical wall by a quadrant of a circle of sufficient radius, may be found answerable. Such a form will prevent to a considerable extent the danger of reaction, by causing the alteration in the direction of the wave to take place at that part where the wall is strongest, and which is also at the greatest possible distance from the toe or curb-course. If the materials are abundant and of a rough nature, a cycloidal wall with vertical and horizontal tangents, somewhat similar to that erected at Trinity, near Edinburgh, may be adopted with advantage. But a very serious objection to all forms of curved walls, unless the radius be large, is the weakness which results from the use of wedge-shaped face stones. The impact of the sea upon materials of that form may be compared to a blow directed upwards against the intrados of a stone arch—the direction, of all others, in which the voussoirs are most easily dislocated. This action can only be successfully resisted by very careful workmanship in the dressing and the setting of the backing. Another objection, applicable to all except tideless seas, such as the Mediterranean, arises from the varying level of the surface of the water; for that profile which may be best at one time of the tide cannot be equally suitable at another.

Works for Protecting Land in Open Estuaries.—In other cases in estuaries more open to the sea, works of a stronger kind are required. Figs. 9 and 10 are a plan and section of a protection which was adopted on a line of shore composed of shingle. Jetties projecting from the shore had at first been used to collect the shingle, but in heavy seas the waves were led along the jetties, and had a hurtful effect at their roots where they joined the beach. A continuous line of piling and planking was accordingly adopted, combined with occasional jetties, and this has proved very successful. In proof of this, it has been found that wherever the upright piling and planking have been formed, there was no influx of anything beyond spray upon the adjoining land, but that at all other parts of the coast (which is about 6 miles in length), where the face of the beach is sloping, the water passed freely over in considerable depth, carrying drift timber far into the fields,

Fig. 9

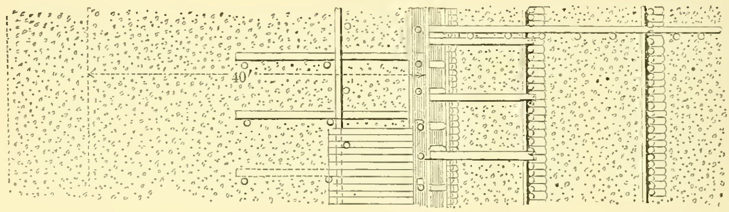
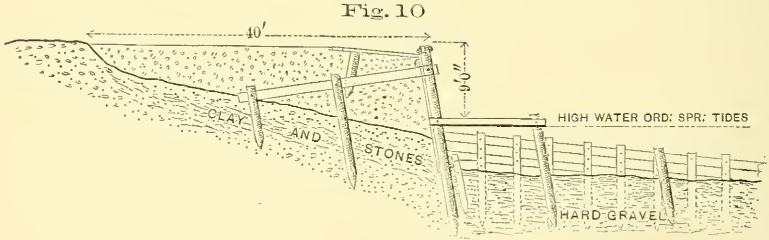


Fig. 10



and in some places heavy shingle to the depth of 2 feet. The problem to be solved was to oppose an obstacle which should throw back the sea; and the upright face, from which the heavy portion of the sea recoils, was found to do this better than the sloping face. In order to encourage the collection of shingle, a second line of longitudinal piling was, at some places, formed in front, and parallel to the main line of defence; and the works now described have been found a very effective defence on a line of shingle beach, exposed to a considerable sea, on the shores of the Bristol Channel.

In designing all such works, however, the engineer must be guided by the formation and exposure of the shores, the kind of materials most easily available, and above all the value of the property endangered, as every engineer must know by experience that in some situations protection can only be secured at a cost out of all proportion to the benefit which it would confer.

The notable difference between the subject to which my attention has been directed by the Council, as compared with the other lectures, is the extreme want of exactness which characterizes the whole subject. In no other branch of engineering is there so great a prevalence of what may be called "rule of thumb." Indeed, hardly any attempt has been made to obtain observations, reducible to a formula, by which numerical results can be calculated as to the force of waves; the height of waves, in relation to the depth of water in which they move; the reductive power of harbors, by which the waves after entrance are diminished in height; the shelter due to protecting breakwaters, and the like. I would strongly counsel young engineers to do their best to supply these *desiderata.* Here is a field where they may do good service to the profession and in the interests of mankind. Here is a branch of engineering where we are still in want of facts, and to a far greater degree in want of the means of scientific calculation. No one knows better than myself the difficulty of the task, for I have had a large experience, and have been too often baffled in my best endeavors to obtain coefficients. But we must not look to difficulty, we must look to utility; and I see no branch where the patience, the ingenuity and the scientific accuracy of observers will be likely to produce more useful results than the one to which I refer. Lastly, I would say a word of welcome to a new book: Mr. Vernon-Harcourt's "Harbors and Docks." It is (particularly on the historical side) a treasury of facts, and forms a large addition to the historical library of the marine engineer.

ENGLISH AND AMERICAN RAILROADS COMPARED.

By EDWARD BATES DORSEY, M. Am. Soc. C. E.

From the Transactions of the American Society of Civil Engineers.

In the opinion of the author, neither the English or American railroad is perfect in itself, if the object of a railroad is to give the greatest amount of comfort to the passengers for the least amount of money, and the cheapest freight charge to the shipper. In this light, the Pennsylvania Railroad comes nearer perfection than any other, but it has the serious fault of many level road crossings. All other large American railroads have, in addition to this defect, that of the absence of the block system. With these two faults alone, they are far from being perfect, to say nothing of minor improvements required, such as good station buildings, etc.

Although the English cars are far from being as comfortable for travelers as the American, yet the English engineer can do but little now to remedy it, owing to the low and narrow cars he is obliged to run. Perhaps the most that could be done would be economizing in the cost of motive power, the general introduction and use of the American baggage-check on all connecting lines, thereby increasing the comfort of passengers, and also saving a large expense to the railroads in saving the cost of many unnecessary porters; warming the cars in winter; general use of the bogie truck under passenger cars, thereby diminishing the constant jarring motion now so great in them.

The English road-bed, superstructure and block-signaling system are all that could be desired.

From superficial observation, it is difficult to say what is the cause of the great additional cost in motive power in operating the English railroads, when it should be much less than that of the American railroads, as, owing to their average superior construction, with easier grades and curves, it should not be much over half, instead of being nearly double.

Apparently the most prominent cause of this increased cost is the great speed and small tonnage of the freight trains, and too many passenger trains lightly loaded.

Perhaps the American bogie-truck rolling stock runs with less friction than the rigid wheel-base rolling stock used on the English roads.

The English railroads have cost per mile more than three times as much as the American, yet they only save eight per cent. of the annual operating expenses. In other words, to save one-twelfth of the annual operating expenses, the cost of construction has been increased more than three times. The preceding comparison would be still more striking if we brought into calculation the comparative cost in the two countries of the different items included under the heading of "Maintenance of Way," "Locomotive Charges," and "Repairs of Carriages." Probably 90 per cent. of these are made up of labor, fuel, iron, steel, etc., all of which would average, in 1883, fully one-fourth higher in the United States than in the United Kingdom. This speaks very well for the American system, that, notwithstanding it costs much less to construct, after paying higher prices for labor and materials—and for financial reasons the location is often faulty, and the superstructure of perishable materials—yet it is operated for less than the English roads are, when due allowance is made for the difference in the price of labor and materials that enter into operating expenses. Notwithstanding these disadvantages for similar accommodation, the passenger rates and freight charges are much less on American than on English railroads.

One of the principal items of the greater cost of English railroad construction over the American, is the necessity of having much straighter alignment or easier curves, so that it can be safely operated by the rigid and long wheel-base rolling stock in use there.

The Baltimore & Ohio Railroad is a sample of what can be done with the American rolling stock. This road is built through a very difficult and rugged country, which compelled a very poor alignment, with nearly one-half of the entire length in curvature, which curves run up to 600 feet radii, and long grades running up to 120 feet per mile. The country affords no natural advantages whatever. Yet, with all these drawbacks, this road does a very large and profitable business, paying annually ten per cent. dividend, and running passenger trains safely at very high speed.

All this is done on a road that could not be operated with rolling stock built on the English system. The extra cost of enlarging these curves to adapt them to English rolling stock would be so great as to be commercially impracticable. It is not difficult to appreciate the great difference in cost of construction, in an extremely rough country, of a railroad which curves 600 feet, or 2,640 feet radii.

Unquestionably the American system of construction is the best for new countries, or where cheapness of construction is desirable. The American rolling stock, with the bogie-truck, will run safely and rapidly over roads of inferior construction, or sharp curves that would be impossible for rolling stock constructed on the English type of long and rigid wheel base. The American type is especially adapted for military purposes. During the late American war some military railroads were operated successfully, with the ordinary American rolling stock, with curves of 50 feet radii. The New York Elevated Railroad has been operated for years (it transported last year 97,000,000 passengers) without accident, and has many curves under 100 feet radius. Through an ordinary rough country, a railroad to be operated with the American type of rolling stock could be constructed in one-fourth of the time, and for one-fourth of the money that one suitable for the English rolling stock could be built.

It would certainly pay the management of the English railroad companies to investigate the cause of the extra cost of motive power on their roads, and, if possible, remedy it. If this can be done, they will be able to *decrease their operating expenses* over 8 per cent., without making any changes whatever in the present prices. This will enable most companies to *increase their dividends* largely—probably over 4 per cent.

For what *is* done in the United States *ought* to be done in the United Kingdom.

CALORIFIC POWER OF FUEL.

By JOJI SAKURAI, Professor of Chemistry, Tokio University, Japan.

From "The Chemical News."

In "Watts's Dictionary, "vol. ii., there is an excellent article on "Fuel," written by Dr. Benjamin H. Paul, where a method for calculating the calorific power of fuel is given. Thus, after speaking of the relative calorific power of hydrogen and carbon, and of the effects of oxygen contained in a fuel, he says on page 723:

"The relative calorific power of fuel may be calculated by means of the following formulæ, in which p represents the relative calorific power, and CHO represent the amounts of carbon, hydrogen, and oxygen in one part of the fuel:

"1. Fuel containing only carbon

$$p=C.$$

"Fuel containing carbon and hydrogen

$$p=C+4.265\ H.$$

"3. Fuel containing carbon, hydrogen, and oxygen

$$p=C-\tfrac{8}{8}O+4.265\ H,$$

$$\text{or, } p=C+4.265(H-\tfrac{1}{8}O)$$

"If it is desired to express the calorific power of fuel in heat units, the amount of carbon and the amount of available hydrogen in one part of the fuel are to be respectively multiplied by the numbers expressing the calorific power of carbon and of hydrogen, and the sum of the two products represents the relative calorific power of the fuel in heat units:

1. $p=8080\ C.$
2. $p=8080\ C+34462\ H.$
3. $p=8080\ C+34462\ (H-\tfrac{1}{8}O)$."

Then he gives a table, in which the relative calorific powers of several combustibles are given, as calculated from their composition according to the above formulæ, and from which I here reproduce a few figures:

Fuel.	Composition of Fuel.				Calorific Power in Heat units.
	Carbon.	Hydrogen.	Oxygen.	Ash.	
Hydrogen........	....	1.00	....	....	34,462
Marsh-gas.........	0.750	0.250	....	....	14,675
Olefiant gas.......	0.857	0.143	....	....	11,849
Av. Welsh coal....	0.838	0.048	0.041	0.090	8,241

The number 14,675, which is the sum of the quantities of heat evolved by carbon and hydrogen separately, is therefore regarded as the relative calorific power of marsh-gas, a view which is similar to stating that marsh-gas is a mixture of carbon and hydrogen.

As everyone knows, the researches of Thomsen and Berthelot have shown us that the calorific power of a hydrocarbon is not equal to the sum of the quantities of heat evolved by the carbon and the hydrogen separately,—that, in fact, we must take into account the heat which is evolved or absorbed by the separation of carbon and hydrogen from each other. According to Thomsen, the heat of formation of marsh-gas is:

$$CH_4 = +20,414.$$

This quantity of heat is therefore absorbed during the decomposition of 16 parts of marsh-gas into carbon and hydrogen, and hence the actual heat of combustion for 1 part of marsh-gas must be about 1,276 units less than the number found in the above table.

Again, when olefiant gas is decomposed into carbon and hydrogen there is *evolved* some heat, and hence the actual heat of combustion of that hydrocarbon must be greater than that in the table. According to Thomsen we have:

$$C_2H_4 = -10,880.$$

Hence, the decomposition of 1 part of olefiant gas into carbon and hydrogen evolves about 389 units of heat, and hence the calorific power of olefiant gas should be 12,238 heat units.

Lastly, coal is evidently not a mere mixture of carbon, hydrogen, etc., but is a chemical compound of some sort, and hence the calculation of its calorific power according to the above formulæ is not only useless, but is also erroneous.

There is, so far as I am aware, no formulæ by which the calorific power of fuel may be calculated. The only way is to resort to actual experiments.

It is unfortunate that no correction has been made in the subsequent volumes of "Watts's Dictionary" as to the point above referred to; nor has anyone, so far as I can ascertain, pointed out the error.

Not only is that the case, but even in some of the very recently published books we read similar statements. For example, on page 43, Part II., of Mr. C. J. Woodward's excellent little book called "Arithmetical Chemistry," the following statement occurs:

"The calorific power of coal, of which the percentage composition is given, is calculated in the same way (that is, by adding together the calorific powers of carbon and hydrogen contained in the coal: J. S.), but, of course, any nitrogen or ash the coal may contain must be disregarded; and, further, if oxygen be present in the coal, a quantity of hydrogen or carbon, or the two together, sufficient to combine with this oxygen, must be deducted."

Periodical Movements of the Ground as Indicated by Spirit-levels. The sixth year (1st October, 1883 to 30th September, 1884) of these investigations presents features almost identical with those of the preceding one; the curve, traced by the east end of the level oriented east-west, shows a gradual fall of 15 seconds to the end of December, 1883; it then fluctuates up and down till the middle of May, having reached its greatest depression, viz., 21.59 seconds, on 24th, 27th and 29th of April. Its subsequent maximum summer rise—reached on 21st–22d September—was only 19.39 seconds. It is worthy of remark, that in four years out of six, the east end has shown not only a smaller subsequent recovery in summer than its fall during the preceding winter, but also an annual diminution in the amount of such recovery, and this agrees with observations made over a period of twenty-three years by Professor Hirsch, at Neufchâtel, where the ground movements indicate three septennial periods, during which the *west* end (not the *east* as at Sécheron) has alternately fallen and risen; but eventually has fallen more than it has risen. The mean annual depression at Neufchatel for these twenty-three years has been 1.59 second, while at Sécheron that of the east end has been 13.44 seconds; if, however, the exceptional cold winter of 1879-80 be omitted, it really amounts to 1.27 second, which is a very fair agreement. Future observations will show if this analogy is maintained, and especially if the septennial periods will also occur at Sécheron.

The oscillations of the ground from east to west in 1884 confirm the remark made last year, that it is the continuity of a certain mean temperature rather than the absolute dates of the maximum and minimum temperatures which influences the epochs of the extreme ground-movements.

The oscillations shown by the level oriented south-north have been as usual less pronounced, their amplitude being 7.26 seconds as against 6.56 seconds last year; and while the south end regularly falls every winter, but gains on this fall little by little each summer, the anomaly of its not following the variations of the air-temperature is still repeated.

THE STEEL PROBLEM.

From "The Engineer."

The history of steel supplies numerous examples of failure. Mr. Maginnis' experience only differs in magnitude from that of several other engineers. English and Scotch steel are not specially liable to failure. The same peculiarities manifest themselves in American, German, and French steel. Steel makers, in a body, and the majority of steel users, state, and with reason, that, as a constructive material, it is unrivaled for strength and ductility. No one now disputes the accuracy of this proposition. It leaves the solution of the steel problem quite unaffected. That problem is—Why does a material so ductile and so strong split and break? Cracking is the last thing to be expected of it. Toughness is the great specialty of steel. Why should a tough, strong metal crack? This is the question. It does not appear that any answer has ever been given which is accepted as conclusive. To add another theory to the many attempted solutions of the steel problem can do no harm; it may do good.

In this article will be maintained the following thesis: The fracture of steel boiler and ship plates is due not to a defect in the material, but to the homogeneity of the metal. This being the case, so long as steel is homogeneous, so long will fractures such as that of the boilers of the *Livadia*, and many others, occur. Nothing that the steel maker can do will prevent their occurrence, because the steel maker has nothing to do with the immediate cause of failure. This statement is to be taken, of course, with limits; that is to say, the steel must be free from notable percentages of sulphur or phosphorus.

It is evident that steel as a constructive material will always be exposed to stresses. These may be either tensile or compressive; more usually the former. For the sake of simplicity and brevity, attention may be given to only one form of steel, namely, boiler plates. When a boiler plate is in place, it is submitted to a tensile strain, and that strain will not be equally distributed through the plate. It would be easy to show that there can be nothing like equitable distribution of stress anywhere in the plate. It will suffice, however, to point out that the matal between the rivet holes is more severely stressed than the metal in the body of the plate. If this is conceded, it follows that some portions of the plate are more liable to fracture than others, in so far as they are more severely stressed.

It is a peculiarity of all materials of whatever kind, that under anything like a constant stress they give way by degrees. That is to say, one portion parts company with its fellow a little before another portion. The interval of time marking precedence of rupture, may be extremely minute—but we have no reason to say it does not exist. It may also be very considerable. Now, it is a special characteristic of all homogeneous bodies submitted to stress *that if they once begin to give way the process will be continuous until it is complete*, provided the stress be kept up. This is the crucial proposition of the theory now advanced. If it is not true, then all that follows in the way of argument or deduction falls to the ground. It is not true of non-homogeneous materials.

If the proposition be true, a crack, however small, once developed in a steel plate, must continue to extend, if the stress is maintained, until fracture is complete.

If the stress is not severe in proportion to the area involved, the crack may not extend for years. If it is severe, the crack may become a complete fracture in a very short time. For this reason a crack may exist in one part of the steel plate, say in the body of it, which will practically do no harm. A similar crack between the rivet holes may produce the most disastrous results. The magnitude of the crack is of no importance; the magnitude of the stress is. The locality of the crack is only of importance in so far as location determines stress.

In glass we find the analogue of steel. It is homogeneous, possessed of great elasticity and considerable strength. It will stand a stress of about 1.25 ton per square inch. It differs from steel more in degree than in anything else. From this cause all the bad qualities of steel are magnified and intensified in glass. It supplies, therefore, ready to our hands an admirable means of illustrating the truth of the propositions set forth above. We have only to start a minute crack in glass to cause its complete rupture, provided the material is stressed. It may be said here that the force required to fracture glass in which a crack has been started by a diamond is out of all proportion small compared to that which steel will sustain. The answer is that the steel will depend on the cohesive strength of the material. Steel is about thirty times as strong as glass; hence, at least thirty times as much force will be required to develop a minute crack into a fracture. It may be conceded, however, that much more will be needed in the case of steel, and yet the main argument will not be affected. It is necessary here to point out that the magnitude of the initial crack is of no consequence in the case of glass. The crack made by a glazier's diamond is so shallow that its depth can only be expressed in thousandths of an inch.

It must be clearly understood that everything and anything that is called a crack in a steel plate is not necessarily mischievous. There are cracks and cracks. Thus, the crack produced by a glazier's diamond is very peculiar. It is in no sense a scratch. A diamond cannot be cut by a lapidary to produce a crack. A diamond ring will not and cannot "cut" glass; it will only scratch it. The cutting diamond is really a chip or flake of diamond—a natural crystal, in fact—and has not a ground-up, but a natural cutting edge, and it requires some knack in applying it to the glass, even then, to use it successfully.

What may be termed a fatal crack in a steel boiler-plate must be strictly analogous to a crack made by a diamond in glass.

That cracks, once started, will extend in steel has been demonstrated over and over again. Armor-plates afford a good illustration. After one has been struck by a heavy shot, the cracks started by the impact of the projectile will continue to extend, the plate making a peculiar singing noise the while. The special developing powers of cracks in homogeneous mixtures are well known, and provided for in daily practice. Thus, a small hole is punched by the corner of a shutter in a plate glass window; there are minute radiating cracks visible. Leave the pane to itself, and the crack will extend under the influence of the vibration due to street traffic. The prudent owner sends for the glazier, who passes a diamond in a circle around the hole outside the longest of the radiating cracks. The damage will not extend beyond this circle, and the worst that can happen is that the circumscribed piece will drop out, when the hole can be stopped by a new piece cemented in. When a crack starts in a fire box a hole is drilled at each end and a rivet put in. The crack will stop at the holes. It ought to be quite unnecessary to extend illustrations of what must be well known and admitted by all engineers. Mr. J. Head, in his address as President of the Institution of Mechanical Engineers, said: "The superior tensile strength and ductility of steel as compared with wrought iron, and its independence in these respects of the direction of fiber or grain, arise from its purity and homogeneity. The molecules composing it, when it is in a fully wrought condition, seem to be in almost absolute contact in every direction. There is no appreciable interposition of cinder or other foreign substance, and they are therefore fully subject to cohesive attraction. But this homogeneity is the cause of extreme susceptibility to tearing strains. Imagine for a moment a piece of steel plate to be composed of a number of molecular columns, side by side, each column being equivalent in height to the thickness of the plate. Let us now apply a splitting force just capable of overcoming the lateral cohesion of two contiguous columns forming the edge of the plate at a particular place. They are separated, and offer no further resistance, and the force is available to act on the next pair of columns. These separate, and the split proceeds. The view that mysterious cracks in steel are all in the nature of tears seems to be confirmed by the fact that in such cases there is never any appearance of contraction at the fractured edges, notwithstanding the general ductility of the metal. This also may, I think, be explained. Let us suppose that one pair of molecular columns in the line of a crack came in its turn under the separating strain, and tended to shorten before parting company. It is evident that the pair of columns last torn apart, and now free from strain, and the next pair ahead, not yet strained, would both act as props, and afford support, so as to prevent shortening of the then strained pair. In this they would be assisted by all other contiguous columns; whereas, if the whole piece of plate were strained equally across while being pulled in two in a testing machine, each molecular column across the line of fracture would be under identical conditions, and none would interfere with the tendency in its neighbours to shorten. Cracks in soft steel plates, unaccompanied by contraction at the fractured edges, must then of necessity be tears; and tears cannot show evidence of contraction. A wrought-iron plate is not liable to tears of this kind, because possibly the cinder which permeates it acts as a sort of padding between the molecular columns. Suppose a similar strain to be applied to the edge of an iron plate, and to leave the first pair of columns separated and just beyond the range of cohesion. If we were dealing with steel, the next pair of columns would now be sustaining the full brunt of the force. But iron being the material concerned, there would be a padding of cinder intervening, and the next pair—or possibly group—of columns would be some distance off. The gap commenced would have to be widened or wedged out, as it were, before the second row or group was strained beyond cohesion; and for this the range of the original force would perhaps be insufficient. To put the case another way. A very finely woven muslin fabric may easily be rent across. But if the threads composing it were rearranged so as to form a coarse net, it would no longer be easily torn, though its combined tensile strength would be unaffected. Mr. Baker, in the course of the paper he read before the British Association, at Montreal, last autumn, said that alarm had been created at the Forth Bridge works by a certain Landore steel plate, 1½ in. thick, which broke like cast iron on being bent cold to the flat radius of 6 ft. He was certain it was not the fault of the material, as a shearing from it had been bent round to a radius of 1½ in., after being made red-hot, and cooled in water. He afterwards traced it to the damage locally commenced by shearing. This could not have extended more than $\frac{1}{16}$ in. from the edge, because planing removed it. Yet it affected the entire width; for the plate 4 ft. 6 in. wide snapped across as easily as a strip 1 in. wide. The difficulty was equally removed by annealing. His practical conclusions were to the effect that the strains initiated by shearing or punching might be fatal to any steel plate, unless removed by planing or rimering, or by annealing. Some time since, a number of steel test pieces were laid on the table of an office adjoining mine, which had all successfully undergone Lloyd's quenching test. That is, each piece had been heated red-hot, then plunged into water at 82 deg. Fahrenheit, and then when cold bent round double, the inner radius of the curve being one and a-half times the thickness of the plate. Several times during the next few days sharp reports like those of a small pistol were heard proceeding from the office. The cause was not immediately detected, but it was afterwards accidentally discovered that some of the test pieces had developed fine cracks across the outer surface of the bend. Although quite sound at first, they had evidently been under severe strain, and their tuning-fork form had caused the sharp report when they gave way. There was no sign whatever of contraction along the fractured edges."

To recapitulate. The failure of steel plates is caused by the formation in them of very minute fissures or cracks of the specific kind needed, and the application of sufficient stress. Thus, for example, a boiler plate is flanged in a ring to take a furnace tube. It is left all night. In the morning the ring is found to have detached itself from the boiler. A little consideration will show that however kindly the metal lent itself to the work of flanging, stresses have been set up in it. The flanging was done while the metal was heated a bit at a time; it was also cooled a bit at a time. We may rest assured that in such a ring civil war is raging among the molecules. The minority try to break loose; they are constrained by the majority. A fissure of the proper kind, no bigger than a hair, once developed somewhere about the bend and off comes the ring. It will be argued that if this were true annealing would be of no use. This is not so. Annealing is of use, not because it prevents the formation of incipient cracks, but because it demolishes the internal stresses which render the cracks operative for mischief. The stress alone, or the crack alone, will do no mischief. Combine them and an extended fracture is certain to ensue.

Incipient cracks of the right sort occur in iron just as they do in steel; but they have no power of extension. The want of homogeneity in the material is fatal to their progress.

It is very doubtful if any advance has been made toward eliminating the uncertain character of steel. For more than twenty years it has been before the world as a material used for shipbuilding and boiler plates, and twenty years ago it manifested the same admirable qualities it does to-day. It also manifested qualities not admirable; Messrs. Harland and Woolf's experience with the *Istria*, for example. There is, therefore, no reason whatever to imagine that any progress can be made in the means of its product tion which will render it quite exempt from such failures as those recorded by Mr. Maginnis and "Snap." Neither is it very easy to see how the boiler-makers or the ship-builders can do much more than they do now. Every precaution should be taken to prevent the formation of incipient cracks—which will be quite invisible in most cases—and to get rid of them if formed. Thus the edges of boiler plates should always be planed and *smoothed*. To merely run over them once and tear off a coarse shaving may do as much harm as good. All rivet holes should be drilled, or at least rimered out to a *smooth* surface. The boring out of flanged rings would probably be productive of great good. The utmost caution should be used, in caulking, to use tools in such a condition that they cannot start cracks.

Nothing new is suggested here. The fact that such precautions have long been used is the best possible evidence of the truth of the proposition put forward at the beginning of this article, and repeated here, namely, that the formation of extremely minute cracks in a homogeneous material like steel is certain to cause ultimate fracture, provided stress is put on the plate. The apparently treacherous nature of steel is due wholly to its homogeneous texture, and until for that has been substituted a non-homogeneous or fibrous texture, steel will remain untrustworthy.

ON THE ORIGIN OF ATMOSPHERIC ELECTRICITY.

By E. GERLAND.

Translated from "Elektrotechnische Zeitschrift" for the Institution of Civil Engineers.

The Author first refers to the theories of Mohn, Fick, Pouillet, Dove, Wettstein, Palmieri, Mühry, Becquerel, Werner, Siemens, Holtz, von Bezolds, Dellmann, and other physicists, regarding the source of atmospheric electricity. These theories may be classed under two groups, viz., one in which the earth is taken to be the source of this electricity, and the other comprising all the theories which regard the sun as the origin of the electrical phenomena observed in the earth's atmosphere.

Dove was the first to point out that electricity may be generated by the friction set up when aqueous vapor is formed in the midst of air. This was inferred from the fact that electricity is developed in considerable quantities when sand and dust are whirled about in the air.

Palmieri observed that atmospheric electricity increased as soon as the relative humidity of the air became greater. In the mist, the increase was more marked, and in hail, rain, or snow, the tension became so high that sparks were produced.

To the second group belong the theories of Becquerel and Werner Siemens. The former scientist assumes that the hydrogen given off by the sun is strongly electrified, the electricity in a diminished state of tension being carried into space by radiation until it reaches the earth. Goldstein's experiments have shown that such radiation, analogous to that of light and heat, is possible. Werner Siemens' hypothesis is based on Sir William Siemens' theory of the conservation of solar energy. The basis of this theory is that interplanetary space is filled with highly rarefied gaseous matter, which is drawn towards the polar surfaces of the sun, and during its approach thereto the gases composing this attenuated matter become compressed. On reaching the photosphere, these gases meet with such conditions of temperature and pressure as cause them to flash into flame. The products of their combustion flow towards the solar equator, and are by centifugal force projected into space. Dissociation is then effected by means of solar radiation, and the gases resulting therefrom are again attracted toward the polar regions of the sun, and the cycle of operations repeated.

Werner Siemens assumes that the actions of the gases on the photosphere produces enormous friction, the photosphere thereby attaining a high electric potential of positive sign, whilst the gases become oppositely electrified, and carry this electrification with them into space. As the earth and other planets are probably conductors, each of these bodies forms, in conjunction with the sun, a stupendous collecting apparatus, the insulating medium being the intervening empty space. The potential of the earth is dependent on that of the sun; terrestrial magnetism as well as the northern and southern lights, are mainly due to solar electricity.

Holtz has raised various objections to this theory, and the author points out that it gives no satisfactory solution respecting the source of the electricity of thunder clouds, and does not take into account such phenomena as the diurnal electric variation and, at places where rain is falling, alternate zones of negative and positive electricity surrounding a positively electrified center.

In the author's opinion, these difficulties do not obtain when the earth is taken to be the source of the electricity of clouds, and this hypothesis would have been more generally accepted, had the fact been recognized that the generation of the observed positive electricity of a cloud implied the presence of an equally large quantity having a negative sign. Wettstein and Siemens are the only two physicists who have paid sufficient regard to this, and indicated by what means the negative charge is removed.

The careful observations of von Bezolds show that at the outbreak of a thunderstorm the atmospheric pressure is at a minimum, and the temperature at a maximum. The formation of the storm, is due, therefore, to an ascending current of air, which is capable of rapidly separating the electricities. By means of this upward current warm and humid strata of air are conveyed to colder regions, where the aqueous vapor is condensed with more or less rapidity; this process is accompanied by a development of heat caused by the vapor giving out its latent heat of vaporization. The increase of temperature causes the layers of air to rise still higher, and the vapor becomes more rapidly condensed; raindrops are thus formed, and these drops fall quickly towards the earth. Their velocity relatively to that of the air becomes so great that electricity is generated, either through friction between the drops and the air, or through the formation of the drops, which are charged with electricity of one sign, whilst the air is electrified oppositely. If the velocity of the ascending air-current is sufficiently great, the potential of the cloud may become so high that a discharge takes place between it and other clouds or the earth; the latter having become negatively electrified by induction at that portion of the surface over which the cloud rests. The discharge may be effected gradually by the raindrops, or suddenly with the accompaniment of a flash of lightning, the nature of the discharge depending on the velocity of the current of air. The increased rainfall which often occurs after lightning may be ascribed to a sudden increase in the velocity of the air-current, and a consequent larger formation of raindrops. A greater quantity of electricity is thereby generated, and a sudden discharge to earth takes places, whilst the raindrops require a longer time to reach the ground. Palmeiri found that the electrification of thunder-clouds was always positive, when no inductive effect was exercised. The phenomenon observed by Dellmann, viz., a cloud with a negative center surrounded by a zone of positive sign, was no doubt due to induction.

The author considers that the various circumstances which precede thunderstorms favor his theory that the source of the electricity is to be looked for in ascending currents of air which cause rapid condensation of aqueous vapor; and he describes, in support of his idea, the various phenomena observed during the thunderstorms of this latitude, which have, according to Dove, their origin in the ascending and descending equatorial currents of air. The author proposes to add to these two classes a third, which shall embrace storms arising from predominant local currents, or summer storms. In Holland, he had, on a stormy evening in winter, the opportunity of observing a phenomenon, which appeared to negative the idea that the electricity of thunder-clouds was due to the inductive influence of the earth. The night was tolerably clear and starlit, when, at a certain moment, a cloud scarcely large enough to cover the constellation of Ursa Major was urged by the west wind quickly across the sky. The cloud had the form of a nine-pin, the point being turned toward the direction from which the wind was blowing. As several flashes of forked lightning passed from the base of the cloud to its point, each flash being followed directly after by loud peals of thunder, the cloud could not have been very distant, or of great extent. No rain appeared to fall from it, but there was scarcely light enough to determine this with certainty. On the supposition that the cloud was charged by induction from the earth, the springing across of the flashes from one part of the cloud to the other could only be accounted for by admitting that a marked change in the electrical condition of the earth took place before each flash, whereas the phenomenon is easy of explanation when attributed to an ascending current of air which caused a small quantity of cold air to be forced into the equatorial current.

THE PANAMA CANAL.

The following account of the condition of this work is an abstract from a review in *Science*, of the history of the project, by J. C. Rodrigues.

The canal congress estimated the cost of a sea-level canal at 700,000,000 francs, or £28,000,000, although a sub-committee had practically put the cost at 1,040,000,000 francs, and added that the "execution of such works, and principally that of such deep cuts, the stability of which is problematical, as well as the operations relating to the course of the river Chagres, constitute a complication of difficulties that it is impossible to estimate." There was added to the prime cost 25 per cent. for unforeseen expenses, 5 per cent. for expenses of banking and administration, and 3 per cent. per year for interest during construction. An "international commission" visited the isthmus in 1880, and reported that the canal would cost 843,000,000 francs, without preliminary, banking, and administrative expenses, and interest during construction, and estimating contingencies at but 10 per cent. They reported 75,000,000 cubic meters to be excavated, in place of 46,000,000 previously estimated. This estimate of cost M. de Lesseps first cut down to 658,000,000 francs, and later on to 530,000,000 francs. A more extended acquaintance with the problem has raised the estimate of quantity to 125,000,000 cubic meters.

The dredging through the low alluvial lands near the sea, and the formation of harbor works, would, of course, present no difficulty; but the two rock-cuttings —the deepest at the Culebra, 820 feet in width at the top, containing from 25,000,000 to 30,000,000 cubic meters, of which but a small portion has yet been removed; and the Emperador cut, not so deep, but containing about the same quantity of rock—are very formidable obstacles, which will, at the rate work has as yet progressed, require many years to overcome. There is also the uncertainty whether little or much water will be encountered in the lower portions of these cuts. The removal of rock under water will swell the cost greatly.

The Rio Grand and Rio Obispo cross the canal eleven and seventeen times respectively, and hence must be diverted, calling for thirty miles of new channels. The most formidable obstacle, however, and one which leads many engineers to doubt the possibility of the maintenance, if not the construction, of the canal, is the controlling of the tremendous floods of the upper Chagres—a stream which, in the dry season, has a depth of but two feet, but which, in the rainy season, becomes a raging mountain torrent, rising sometimes in a few hours to a height of 40 feet, and sweeping down immense quantities of *débris*. The projected line of the canal is first crossed by it at Gamboa, at an elevation of about fifty feet above the bottom of the canal; from Gamboa to the sea the canal is crossed by it twenty-nine times. It is evident that some most substantial and expensive works are needed to restrain or divert the flood waters of the Chagres, or the canal will be ruined by its irruption. An immense dam of masonry or earth, or of both materials, has been proposed, near Gamboa, a mile in length and from 150 to 200 feet high at its highest point, to impound and store up the flood in an artificial lake, from which it shall escape more gradually through sluices and channels provided for the purpose. The storage capacity of this reservoir is estimated at 6,000,000,000 cubic meters, which is not too much for a watershed on which a depth of five and one-half inches of rain has been known to fall in four and one-half hours. The occurrence of a second tropical rain, before the first has had time to drain away, might be disastrous. This difficult problem, which was pointed out and dwelt upon by some of the delegates to the congress, but was apparently passed lightly over by the majority, seems still to be unsolved at the hands of the French engineers, although the completion of its study has been promised from year to year.

The Panama railroad was purchased by the canal company; dwellings, hospitals and workshops were erected; dredges, machinery and tools were procured; and excavating was begun. Considerable earth and some rock have been removed. Rapid progress has been promised from time to time, but has not been attained; 2,000,000 cubic meters per month were hoped for, but 800,000 cubic meters have not been removed in any one month, and from 1881 up to May, 1885, the amount was only 12,376,000 cubic meters. The amount of material to be moved was first placed at 46,000,000 cubic meters, then 75,000,000 cubic meters, has now swelled to 125,000,000 cubic meters, and good judges believe this quantity to be much too low. M. de Lesseps has raised amounts as follows: 50 per cent. on the shares of the company, 147,500,000 francs; loan of 1882, 125,000,000 francs; loan of 1883, 300,000,000 francs; and loan of 1884, 193,602,500 francs; making, in all, 766,192,500 francs. He has now applied to the French government for permission to issue new canal bonds to the amount of 600,000,000 francs, and proposes to call to his aid a lottory. A further call on the shareholders is also to be made. Discount and interest charges will amount to a formidable sum. One observer puts the time required to finish the canal at six years, another at twelve, and still others at twenty and even fifty years. Mr. Rodrigues fortifies his statements by citations from official documents, and from reports of United States officers and others, who have repeatedly inspected the progress of the work. He does not hesitate to predict the failure and bankruptcy of the present company within a short time.

The *Journal of the Society of Arts* describes a plan for rendering paper as tough as wood or leather, which has been recently introduced on the Continent; it consists in mixing chloride of zinc with the pulp in the course of manufacture. It has been found that the greater the degree of concentration of the zinc solution, the greater will be the toughness of the paper. It can be used for making boxes, combs, for roofing, and even in bootmaking.

ON THE EFFECT OF ALTERNATE HEAT AND COLD ON IRON, STEEL AND COPPER.

By EDMUND WEHRENFENNIG.

From "Organ für die Fortschritte des Eisenbahnwesens."

Translated for Abstracts of Institution of Civil Engineers.

It is well known that wrought-iron or steel bars, after being first heated and then suddenly cooled, decrease in length, as well as that in the case of cast-iron the opposite result takes place, viz, an increase in length. Copper, in this respect, behaves in a similar manner to cast-iron. The author made a large number of experiments, with a view of determining the amount of respective increase or decrease in length for special practical purposes, but his researches being extended beyond what was originally intended, he determined to treat the matter more scientifically.

Experiments with Wrought-Iron.—These experiments were made on round bar-iron, ranging from 2.38 inches in diameter to wire 0.04 inch thick. The bars were subjected to different degrees of heat and then suddenly plunged into cold water, or cooled slowly in the air, or in other cases left to cool down under ashes. A series of experiments were made in which, in one case, the iron was heated for five hours, in the second case for thirteen hours, and in the third for eight days during ten hours per day, the furnace cooling down during the night.

Experiments were also made with flat iron and plates.

The following is a summary of the results of these experiments:

1. A higher temperature imparted to the iron produces greater results than a lower temperature.

For example, in the experiments made with bar-iron 1.04 inch × 1.04 inch in section, the diminution amounted to 0.023 per cent. after the bar had been heated to from 570° to 750° Fahrenheit and then plunged into water; whilst in another case, where the temperature to which the iron was subjected exceeded this degree, the decrease in length measured 0.087 per cent.

2. Rapid cooling and great range of temperature increase the amount of diminution.

3. The length of time during which the metal is subjected to a high temperature greatly influences the amount of contraction.

4. The form of the metal is also an important factor, as shown by the following result:

	Inches.		Per cent.	
Round bar-iron	2.36–1.38	diameter, decreased in length by	0.069	Mean of thirteen experiments.
"	0.79-0.67	" " "	0.065	
"	0.31–0.20	" " "	0.066	
" wire	0.12–0.07	" " "	—0.025	

Whilst, therefore, the heavier section of bars decrease, almost uniformly the wire increases in length.

In the case of two iron plates, one 0.51 in., the other 0.20 in. thick, the former decreased in length and breadth but increased in thickness, while the latter increased in all its dimensions.

Experiments with Steel.—Ordinary steel under the influence of heat and cold behaves in a similar manner to wrought iron, but some steels on being subjected to this treatment neither decrease nor increase perceptibly in any of their dimensions.

The following are the results of experiments repeated three times on a bar of steel of 2.28 in. by 1.18 in. section:

	Per cent.
Diminution of length after first time of heating, and then cooling under exposure to atmosphere	0.001
" " second " " water	0.125
" " third " " "	0.107
" " fourth " " "	0.096
Total diminution..........................	.329

The author gives an account of several experiments made with steel tires, and proceeds to describe the—

Experiments with Copper.—A copper rod, 5.871 feet in length, with a section measuring 2.18 inches in diameter, together with one iron and two copper wires 0.11 inch thick, and of the same length as the copper rod, were heated to a high temperature and then plunged into water, with the results that,

	Inch.
The copper rod increased in length by..	0.138
" " wires " " ..	0 303
" iron wire " " ..	0.177

Experiments with Cast-Iron.—Bars of cast iron:

23.62 in. long,	7.32 in. wide,	1.65 in. thick.
20.00 "	7.32 "	1.65 "
20.04 "	7.32 "	1.65 "

were heated and then allowed to cool by exposure to the atmosphere, or by plunging into water, thereby producing a mean increase of length of 0.051 per cent.

The behavior of brass under this treatment is similar to that of wrought iron, only more marked.

The rest of the paper is devoted to exhaustive speculations as to the cause of the respective contraction and expansion of the building and warehouses. The two larger kilns, of 1,000 barrels capacity each were oval on plan, and the two smaller ones, of 500 barrels capacity, were circular. The larger kilns had eight furnaces, four on each side, and the smaller kilns four furnaces. The kilns were draw-kilns, or perpetual kilns, 45½ ft. in height, and having a railway running above them, for loading in the cement-stone in 2-ton charges from the mine. The space below the draw-gates is sufficiently large to cool the calcined rock to a proper degree for handling in wooden cars. The kilns are drawn every two hours, and filled with fresh rock once in twenty-four hours. The calcined stone, after being crushed, passes by an elevator to the top of the mill-house. The mills are self-feeding by spouts from above. Instead of running horizontally, they are set edgeways on horizontal spindles. The stones are 30 in. in diameter, and each consists of a single block of the best French burr; the runner has a speed of five hundred revolutions per minute. Each mill, when in good trim, will grind fifteen barrels per hour of the standard fineness. The wear of the stones is so great that they require to be dressed after the grinding of each one thousand barrels, and should preferably be dressed after grinding five hundred barrels. The power for the mill is furnished by an engine of 210 H. P., with two tubular boilers. Rope gear is used to avoid extra engines for hauling. The wire rope, under severe and intermittent strain, runs at the rate of about 2,400 ft. per minute. The ropes are ⅝ in. in diameter, of iron wire with hemp center; the pulleys are 5 ft. in diameter, fitted with rubber filling. Steel wires were first employed, but found not to wear so well as those of iron. Particulars with respect to water supply from an artesian well follow, and also as to the use of water under a 90-ft. head to serve the drills. The following analyses are diven of the rock and of the cement:

I. Analysis of Rock by Professor Blaney, of Chicago.

Carbonate of lime	42.25
" magnesia	31.98
Clay and insoluble silica	21.06
Iron and alumina	1.12
Silica	0.06
Water	1.07
Total	97.54

II. Analysis of Cement by G. Bode.

Lime	33.67
Magnesia	20.98
Alumina	9.92
Silicic acid	35.43
Total	100.00

The highest chimney yet built in the world has recently been completed at the Mechernich Lead Works in Germany. The whole height of the structure is approximately 440 ft., 11 ft. of which is underground. The subterranean portion is of block-stone, 37 ft. square in plan. All the rest is of brick. The plinth or lower part of the chimney above ground is 34 ft. square, so that the height of the shaft is nearly thirteen times the lower diameter. The exterior diameter of the shaft at the top is about 11½ ft. The flue is 11½ ft. at the bottom and 10 ft. at the top. Hitherto the highest chimney in the world has been that of the St. Rollox Chemical Works, near Glasgow. This is 434 ft. high.

ON EXPLOSIVE GASEOUS MIXTURES.

By MM. BERTHELOT and VIEILLE.

Translated from "Annales de Chimie et de Physique" for Abstracts of the Institution of Civil Engineers.

These experiments were made to determine the pressure developed and the heat generated by the explosion of various gaseous mixtures in closed vessels. Tables of results are given, and from them the authors deduce the limits of temperatures of combustion, dissociation and the specific heats of the gases at very high temperatures. The results, methods of experiment and calculation are discussed in eight papers.

1st. *On the Calculation of the Temperatures of Combustion, the Specific Heats and Dissociation of Explosive Mixtures.*—This paper is the continuation of a memoir by M. Berthelot in 1877, and contains a theoretical consideration of the principles which have guided the authors in these investigations.

Given the pressure P, developed by the explosion of a gaseous mixture, the temperature of combustion is determined by the method of limits. In the case of no dissociation, a limit above or equal to the real temperature of combustion is given by the formula

$$t_1=273\left(\frac{\text{P}1}{\text{H}g}-1\right),$$

where H is the initial pressure at 0°, and g is the ratio of the volume occupied by the burnt products completely combined to that of the same bodies entirely dissociated. If the initial temperature be above zero, say T,

then $$\text{P}\left(1+\frac{\text{T}}{273}\right)$$

is used instead of P in this formula, which is deduced from the laws of Mariotte and Gay-Lussac. When there is complete dissociation and none of the products really combined, another limit, t_2, below the temperature of combustion, is found from the equation

$$t_2=273\left(\frac{\text{P}}{\text{H}}-1\right).$$

The real temperature of combustion lies between these limits t_1 and t_2. which are brought much closer by the presence in the mixture of inert gases, such as nitrogen—in the case of combustion by means of air. Two sorts of systems are considered. Reversible systems, where the compounds formed by combustion can by dissociation be split up into the original components: such are CO_2, forming CO and O, and water-vapor giving H and O. In non-reversible systems dissociation does not produce the original components. Thus a mixture of cyanogen and oxygen, on complete combustion, yields CO_2 and N, whilst dissociation tends to produce O and CO or even free carbon. Knowing Q the quantity of heat generated by complete combustion at constant volume, another limit t_4, intermediate between the preceding ones, is calculated for reversible and a few non-reversible systems. The mean of t_1 and t_4 gives a close approximation to T, the temperature of combustion.

Then the total heat Q divided by the values t_1, t_2, t_4, T, gives a set of corresponding limiting values, c_1, c_2, c_4, C, of the apparent specific heats of the system at constant volume between 0° and T. The apparent specific heat includes the specific heat properly so-called and the heat given up by the recombination of the dissociated components. The mean value C, of c_1 and c_4 represents the specific heat. This applies to such gases as CO_2 and water-vapor, even when mixed with inert gases like N or with hydrocarbons. Thus values of the specific heat at constant volume of different systems are deduced for temperatures ranging between 1,700° and 5,000° on the air-thermometer.

When two elementary gases combine at constant volume without condensation, the ratio of the effective temperature t, to the temperature T which would be produced by complete combustion, that is t_1 T, gives the ratio of the volume of the portion really combined to the total volume, and hence determines the dissociation.

Special stress is laid on the results obtained from a group of isomeric mixtures, *i. e.*, mixtures which contain the same elements in different states of combination, but all yielding an identical mixture after combustion.

2*d. Experimental determination of the Pressures developed in Gaseous Explosive Mixtures at the Moment of Explosion.*—The pressures have been obtained by exploding the gaseous mixtures in spherical vessels, and registering on a revolving cylinder the law of the displacement of a piston of known section and mass. Complete data of two experiments are given, with readings taken off the curves at given intervals of time during each experiment. The cooling effect of the walls of the vessels is observed by exploding the same mixture in vessels of different capacities. The results are fairly concordant with those obtained by Messrs. Bunsen, Mallard and Le Chatelier by entirely different methods, so far as the latter extended. The authors have made numerous experiments with forty-two different mixtures of H, O, N, CO, CH_4, NO, cyanogen, ether, &c., and the pressures are recorded.

3*d. Relative Rate of Combustion of different Gaseous Mixtures.*—Three explosion vessels of different capacities and shapes were employed. The maximum pressure observed when a mixture of gases is exploded in a vessel at constant volume is always less than if the system retained all the heat generated by combustion, the loss of heat being due to contact with the walls of the vessel and to radiation. This difference is greater the smaller the explosive-vessel, or the smaller the mass of gas with respect to the vessel, and it is also greater the slower the rate of combustion. The time required for the development of the maximum pressure is generally longer the larger the explosive-chamber, and the greater the distance between the piston and the point of ignition. CO is slower than H, but for cyanogen and hydro-carbons rich in H, the time is about the same as for H alone, and agrees with the calculated velocities of the explosive waves. The velocity of translation of the molecules governs the phenomenon. Assuming that the flame reaches the piston at the moment of maximum pressure, the absolute rate of combustion is about 100 meters per second for hydrogen, 8 meters for carbon monoxide, and 70 meters for cyanogen. This is diminished by an excess of one of the combustible gases, and even more so by the presence of the burnt products. An inert gas like N retards combustion not only by lowering the temperature and thus diminishing the velocity of the molecules, but also by preventing contact between the molecules which act on one another. With a mixture of carbonic oxide and hydrogen in oxygen, each gas appears to burn separately at its own rate, the hydrogen burning before the carbon, and consequently the maximum pressure observed does not correspond with a uniform state of combustion of the system.

4*th. Influence of the Density of Explosive Gaseous Mixtures on the Pressure.*—If, in a gaseous system to which heat is communicated, the pressures vary in the same ratio as the densities, it follows, independently of all hypotheses on the laws of gases: (1) That the specific heat of the system is independent of its density, that is of the initial pressure, and depends solely on the absolute tem perature. (2) That the relative variations of the pressures at constant volume, produced by heat given to the system, is also independent of the pressure, and is a function of the temperature alone. In fact, the pressure itself varies directly as the absolute temperature, and, according to the theory of perfect gases, serves to determine it.

The authors overcame the difficulties attending direct measurements at high temperatures by two methods. One consisted in using a vessel, one part of which was maintained at the ordinary temperature in the air, and the other heated in an oil bath to about 153°, which reduced the density of the gas about a third. The second and more exact method consisted in experimenting on isomeric mixtures. From numerous experiments with isomeric mixtures, under different conditions as to density and heat generated, the observed results confirm the ordinary laws of gases.

The authors conclude that for temperatures up to 3,000° or 4,000° on the air-thermometer:

(1) When a given quantity of heat is communicated to a gaeous system, the

variation in the pressure of the system is proportional to its density.

(2) The specific heat of gases is sensibly independent of the density at very high temperatures as well as at zero.

(3) The pressure increases with the quantity of heat given to the system.

(4) The apparent specific heat increases with this quantity of heat.

5*th. Temperatures and Specific Heats calculated from the experimental results.* —These are calculated by the methods described in the first paper, from the pressure P developed during the explosion, and the total quantity of heat Q generated by the complete combustion of the gaseous mixtures. The mixtures are arranged in four groups, and two tables are given for each group, containing the values obtained for the temperatures and specific heats.

6*th. Specific Heat of the Elementary Gases at very high temperatures.*—The authors agree with Messrs. Mallard and Le Chatelier in the general conclusion, that the specific heat of gases increases with the rise of temperature, and that the simple gases have sensibly the same specific heat at all temperatures. By supposing the increase to be proportional to the temperatures between 2,800° and 4,400°, the authors deduce from their experiments the empirical formula—

$$C = 6.7 + 0.0016\ (t - 2{,}800),$$

which gives the specific molecular heat at constant volume of nitrogen, hydrogen, oxygen, and carbonic oxide. Between 0° and 200° the specific molecular heats at constant volume of these gases are about 4.8, and the authors find this number doubled in passing from 0° to 4,500°, becoming 9.8. The variation takes place at all temperatures; it is inappreciable from 0° to 200°, but increases rapidly at high temperatures. The law of increase of the mean specific heat above 1,600° is expressed by the formula—

$$4.75 + 0.0016\ (t - 1{,}600).$$

The real specific heat at constant volume, *i. e.*, the quantity of heat necessary to change the temperature 1°, is calculated by the formula—

$$4.75 + 0.0032\ (t - 1{,}600),$$

for the elementary gases at temperatures from 1,600° upwards.

The specific molecular heat at constant volume of chlorine is greater than that of the simple gases, being 6.6 between 0° and 200°; also at 1,800° the mean specific heat of hydrogen is 5.1, whilst that of chlorine is 15.3, thus approaching that of carbonic acid, which is about 18.

7*th. Specific Heats of Steam and Carbonic Acid at very high temperatures.*— The mean specific heat of steam at constant volume deduced by the authors from their experiments may be expressed by the formula—

$$16.2 + 0.0019(t - 2{,}000)$$

where t is from 2,000° to 4,000°. The mean specific heat of steam at constant volume between 130° and 230° being 6.65, it is doubled at 2,000° and trebled at 4,000°. The heat of formation of water continually diminishes as the temperature rises. This is partly due to the heat spent in the work of molecular separation without decomposition, and partly to the heat absorbed in decomposition or dissociation. About 3,000° dissociation would absorb at most 6,600 calories, that is, one seventh of the heat of combustion, whilst molecular separation would absorb at least 8,600 calories, or about one-fifth of the heat of combustion at this temperature. These numbers are given with all reserve.

The mean specific heat of carbonic acid at constant volume between 0° and t is given by the formula—

$$19.1 + 0.0015(t - 2{,}000)$$

where t is from 2,000 to 4,300. As in the case of water the results show that the heat of combustion of CO to form CO_2 diminishes with the temperature above 200°. The authors calculate that about 4,500° the heat of combustion would be 28,000 calories, and dissociation would absorb at most 18,000 calories, that is, about two-thirds of the heat, whilst at least 22,000 calories of the heat is absorbed by intra-molecular transformation. Comparing the heat of combustion of H_2O and CO_2 at 0°, they are almost equal, being 58,700 calories and 68,000 calories respectively, whilst at 3,000° they become 26,000 and 38,000. Thus their ratio decreases as the temperature increases, and at very high temperatures the carbon tends to entirely decompose the steam.

8th. *Scales of Temperatures and Molecular Weights.*—The results of the previous Papers are considered. Two air-thermometers are compared, the scale of temperatures of one being determined by the dilatations of volume at constant pressure (or by variations of pressure at constant volume) whilst the scale on the other is determined by the quantities of heat absorbed. At very high temperatures these differ widely from one another, and from similar chlorine—or iodine thermometers, owing to the variations in the specific molecular heats which, especially in the case of chlorine, would point to changes in the ultimate molecular constition of substances hitherto regarded as elementary.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers—January, 6th, 1886 —Vice-President Geo. S. Greene, Jr., in the chair. The ballot was canvassed upon the proposed amendment to the by-laws, substituting in section 24, clause 5, the word "December" for the word "November." The clause will then read:

5th. "Any five members, not officers of the Society, may present to the Board of Direction, on or before December 1st, a list of names proposed by them for officers, which list or lists shall also be issued for ballot."

There were in the affirmative 142 votes, and in the negative 4 votes. This amendment was declared adopted.

The following candidates were elected: As members—Maximilian Ferdinand Bonzano, of Philadelpbia, Pa.; Franklin Ide Fuller, of Portland, Oregon; George Watson Kittredge, of Zanesville, Ohio; Henry Wadsworth Reed, of Waycross, Ga.; Henry Frederic Rudloff, of Caracas, Venezuela, S. A.; Albert John Scherzer, Sonsonate, Salvador, Central America. As associate—Calvin Tompkins, of New York City. As Junior—Harry Lee Van Zile, of Troy, N. Y.

The paper previously presented by Mr. Jos. M. Wilson, M. Am. Soc. C. E., on Specifications for the Strength of Iron Bridges, was then discussed. Written discussions were presented from Messrs. William H. Burr, Mansfield Merriman, S. W. Robinson, George F. Swain, G. Bouscaren, Mace Moulton, A. P. Boller, George H. Pegram, William Sellers, James G. Dagron, George L. Vose, J. B. Davis, and E. Thacher. The paper was also discussed by Mr. C. C. Schneider. It is intended to publish this paper, with the discussions, in an early number of the "Transactions." An abstract of the paper and the extended discussions can hardly be given with justice to the writers.

Engineers' Club of Philadelphia—Record of Eighth Annual Meeting, Jan. 9th, 1886.—The retiring President, Mr. Joseph J. de Kinder, read the annual address. The usual review of the engineering of the past year is given. Special mention is made, with much interesting description in detail, of the following proposed or progressing works: the Panama, Manchester, enlargement of Suez, Corinth, Baltic and North Sea, new Chesapeake and Delaware, Hennepin, Paris and Dunkirk, and Gulf of Siam and Indian Ocean Canals; the reclamation of land in Russia and Missouri and Arkansas; the Baltimore & Ohio at Havre de Grace, Tay, Forth, St. Lawrence, Ohio at Henderson, Ky., and St. John Steel Cantilever Bridges; the Croton and Washington Aqueducts; the Mersey, British Channel, Prince Edward's Island, and Chicago River Tunnels; the Tehuantepec Ship Railway; Railroads in China, Japan, Russia and America; the London and South-western Railway Station; Shipbuilding and Gunnery; the Flood Rock Excavation; Natural, Hydrogen, and Sawdust Gases; the progress in Electric Lighting and Power; and concluding with Water Supply, Sewerage and general Municipal Engineering.

He specially recommends that the latter be made a special question of study and discussion by the Club, and asks if it would not be profitable to ourselves and to the interest of the city if the Club would make the engineering of Philadelphia and its public improvements a leading topic in the future.

The tellers of election, Messrs. E. S. Hutchinson and C. Frederick Moore, reported that the following had been elected officers for 1886:

President—Mr. Washington Jones.

Vice-President—Mr. Thomas M. Cleemann.

Secretary and Treasurer — Mr. Howard Murphy.

Directors—Messrs. Frederic Graff, Rudolph Hering, William A. Ingham, Col. William Ludlow, and Henry G. Morris.

Active members—Messrs. Albanus L. Smith, Samuel T. Williams, Robert E. Pettit, and H. R Cornelius.

Mr. Washington Jones took the chair for 1886 with appropriate remarks.

Engineers' Club of St. Louis.—Prof. J. B. Johnson presented a paper to be read, by title, "The Adjustment of a Quadrilateral."

The secretary read a letter from Mr. Wm. T. Blunt, Sec. Ex. Board of Temporary Civil Engineers' Committee on National Public Works, also one from L. E. Cooley, President of that Board.

Moved and seconded that a standing committee, consisting of five members of this club, be elected to consider and report upon such question as relate to the conduct of our National Public Work, and to act in conjunction with similar committees of other societies. Carried.

Moved and seconded that nominations be made and votes be taken for five, and the five receiving the highest number be declared elected. Carried.

Moved and seconded that the committee elect their own officers. Carried.

The following gentlemen were nominated, and the ballot resulted in the election of Messrs.

McMath, R. Moore, J. B. Johnson, Holman and Ockerson.

Resolved—That the standing committee just elected be entitled the Standing Committee on National Public Works, and that its chairman be a full member of the Civil Engineers' Committee on National Public Works, as suggested by the Cleveland Convention, but no action of this committee shall be held as binding this club until it shall have been reported to and endorsed by the club. Carried.

Moved and seconded that the conclusions of the Cleveland Convention be referred to the standing committee to report at next meeting of the club. Carried.

ENGINEERING NOTES.

Germany has decided upon constructing a North Sea and Baltic ship canal, and the Reichstag will soon be asked to vote the money for it. In referring to the project, the Berlin *Post* says: "Prince Bismarck is not the first statesman who devised a waterway between the German Ocean and the Baltic available for war and trading vessels of the largest size. At the time when Walleusteiu's 'Grand German' schemes seemed to be near their execution, this statesman, who, among his other diguities, was appointed Imperial Admiral, cast about to establish a German sea power on the Baltic, and conceived the idea of uniting both German coasts by a canal running through Schleswig-Holstein. But, with the other high-flying plans of Wallenstein, this idea came to nothing, though it was shortly afterwards taken up by Cromwell, who, when Protector, in close alliance with Sweden, aimed at securing to England by this enterprise the hegemony of the Protestant nations of Northern Europe His plan, indeed, went so far that the line of the projected waterway was actually fixed. Leaving the Elbe, the canal was to follow the Eider, and, passing through the Lake of Schwerin, enter the Baltic near Wismar, which would thus be converted into a kind of Northern Gibraltar. But technical difficulties delayed the commencement of the enterprise, and death snatched away the mighty man before he succeeded in removing the difficulties that stood in his way."

Mr. Benjamin Baker, in his address to the Mechanical Science Section of the British Association, said: "Members of this Section who visited the United States last year not for the first time could hardly have failed to notice that American and European engineering practice are gradually presenting fewer points of difference. Early American iron railway bridges were little more than the ordinary type of timber bridge done into iron, and the characteristic features, therefore, were great depth of truss, forged links, pins, screw-bolts, round or rectangular struts, cast-iron junction pieces, and, in brief, an assemblage of a number of independent members, more or less securely bolted together, and not as in European bridges, a solidly riveted mass of plates and angle-bars. At the present moment the typical American bridge is distinctly derived from the grafting of German practice, on the original parent stock. Pin connections are still generally used in bridges of any size, but the top members and connections are more European than American in construction, whilst for girders of moderate span, such as those on the many miles of elevated railway in New York, riveted girders of purely European type are admittedly the cheapest and most durable. From my conversations with leading American bridge builders, I am satisfied that their future practice and our own will approach still more nearly. We should never think of building another Victoria tubular bridge across the St. Lawrence, or repeat the design of the fallen Tay Bridge, nor would they again imitate in iron an old timber bridge, or repeat the design of the fallen Ashtabula bridge. In one respect the practice in America tends to the production of better and cheaper bridges than does our own practice, and it is this: each of the great bridge-building firms adopts by preference a particular type design, and the works are laid out to produce bridges of this kind. It is an old adage that practice makes perfect, and by adhering to one type, and not vaguely wandering over the whole field of design, details are perfected and a really good bridge is the result. Engiuecrs in America, therefore, need only specify the span of their bridge, and the rolling load to be provided for, with certain limiting stresses, and they can make sure of obtaining a number of tenders from different makers of bridges, varying somewhat in design, but complying with all the requirements With us, on the other hand, it is too often the privilege of a pupil to try his 'prentice hand on the design for a bridge, and it is no wonder, therefore, that many curious bits of detail meet the eye of an observant foreigner inspecting our railways.

The magnificent steel-wire rope suspension bridge of 1,600 feet span, built by Roebling across the East River, at New York, well marks the advanced state of mechanical science in America as regards bridge-building It is worthy of note that, at the second meeting of the British Association, held so long back as 1832, there was a paper on suspension bridges, and the author entreated the attention of the scientific world, and particularly of civil engineers, to the serious consideration of the question, "How far ought iron to be hereafter used for suspension bridges, since a steel bridge of equal strength and superior durability could be built at much less cost?" "I earnestly call upon the ironmasters of the United Kingdom," said he, "to lose no time in endeavoring to solve this question." In this, as in many other engineering matters, America has given us a lead America is, indeed, the paradise of mechanics. When the British Association was inaugurated, years ago, there was, I believe, no intention to have a section for the discussion of mechanical science. Possibly it may have been considered too mean a branch. Even the usually generous Shakspeare speaks contemptuously of "mechanic slaves, with greasy aprons, rules, and hammers"; and our old friend, Dr. Johnson's definition of "mechanical" is "mean, servile." We have lived down this feeling of contempt, and the world admits that the "greasy apron" is as honorable a badge as the priest's cassock or the warrior's coat of mail, and has played as important a part in the great work of civilizing humanity and turning bloodthirsty savages into law-abiding citizens.

As I have had occasion to refer to Canada and America in the course of my remarks, I cannot refrain from expressing the high appreciation which I am sure every member of this section entertains of the cordiality and warmth of our reception on the other side of the Atlantic last year. Such incidents make us forget that differences have ever existed between the two countries.

IRON AND STEEL NOTES.

STEEL.—The *Engineer*, in reviewing the progress of steel manufacture in 1885, says: Probably the most important subject connected with mechanical engineering to which we can refer is steel. No advance whatever has been made during the last ten years towards the elimination of the treacherous characteristics of the metal, and there is no reason to anticipate that it will be better 1886 than it was in 1885. Indeed, there is some cause to fear steel is not so good as it was. Steel made by the Bessemer process at all events does not seem to enjoy the reputation it once did. It would be interesting to know why Siemens steel has come to be regarded by boiler makers and engineers as better, in the sense that it is more trustworthy than Bessemer steel; and it may yet be that the product of the converter will be mainly devoted to rails and tires and axles, while boiler plates will be produced only by the Siemens process. So far as can be known, the unexpected fracture of steel plates is due to the spreading of extremely fine initial cracks in a way very clearly set forth in our last impression, and this can only, we fear, be controlled effectually by giving the plate a fibrous structure. Iron has been much abused for its laminated fracture, but it is the lamination of iron that has enabled it to attain the high position which it long held. The effect of lamination may be made clear by supposing that a boiler, instead of being built up of single plates 1 in. thick, was composed of four plates each ¼ in. thick, put together much as the coils of a gun are In the first case, if a crack was once developed in, say, the outside of the single plate, it would quickly spread inwards, and cause the destruction of the boiler; but the outer plate of a shell built up of four plates being cracked through, the strength of the boiler would only be decreased 25 per cent., and the crack could not spread through the remaining plates. It is for this reason that we look on the metal produced by the Congreaves Company with considerable favor. It is made by putting a number of wrought-iron rods into an ingot mould and pouring steel in. The rods become welded to the steel without losing their fibrous nature. When the ingot is rolled down this wrought iron partakes of the general reduction of section, and thus a plate or rod of very perfect mechanical texture is produced. It ought to be possible, however, to carry this system further, and to produce boiler plates in which iron shall be, so to speak, sandwiched, for the express purpose of stopping the spread of cracks. How these cracks are generated is a very important question. They may be due to the cellular structure of the ingot, the cells being, of course, due to occluded gases. Some of the cells may be quite too small for easy detection, even if an ingot were broken across, and yet develope into a dangerous crack. A very interesting paper, entitled "Théorie Cellulaire des Propriétés de l'Acier," by MM. Osmond and Werth, has just been published in Paris by M. Dunod, Quai des Augustins This does not refer to the gas cells of which we have just been speaking, but to what we may term the microscopical structure of steel. We have not space to quote from this pamphlet at length, but we may state briefly that the theory of the authors, based on microscopical and other researches, is that when heated steel loses its carbon, owing to dissociation, as it cools slowly it recombines with a portion of this carbon, but not all; that some carbon is left free until the steel is tempered, when that carbon before free is re-combined; and that a steel bar really consists of an agglomeration of grains of steel secured to each other by a cement. Speaking of the cooling of an ingot and tracing the structural changes down, the authors say, "Finally, there remains in the fluid state a mixture, more or less complex, commonly dominated by carburet of iron, which solidifies in its turn in the joints of the 'globulites,' and unites them into a solid block—c'est le ciment." The steel may be regarded as in the condition of a number of kernels surrounded each by an envelope of cement, and the strength of the steel depends on that of the cement. It is impossible to do justice in a limited space to the working out and proof of this theory. According to it, the cement not being equally distributed through the material, there may be, so to speak, small centers of weakness in it. We quote the author without translation: "Mais, comme le ciment n'est jamais réparti d'une façon absolument uniforme, certain noyaux peuvent briser leur enveloppe plus mince sous une pression plus faibles, d'autres, qui n'ont pas de'enveloppe sur une ou plusieurs faces, se déforment plus facilement encores; de la ces déchirures parfois visibles â la surface des barreaux d'épreuve, et les bruits que l'on entend pendant l'essai; *chaque cellu'e a en réalité sa limit élastique*, et celle que l'on attribue â l'acier ne correspond qu'un maximum d'un phénomène plus ou moins irrégulier." The author further states that shocks and vibrations, by breaking up the cement by degrees, will gradually reduce a bar of steel to a sort of metallic sand. It will be seen at a glance how important a bearing this theory has, if true, on that which attributes the treacherous fracture of steel to minute initial cracks, as set forth by "L." in our last impression. If the elastic limit varies throughout a bar or plate, then if this limit be once exceeded anywhere over ever so small an area, we may at once have a crack localized for the time being. Nothing but stress is required to develope it.* This theory, too, very satisfactorily explains what has been pointed out by Mr. Parker and others, namely, that the more work we put into a plate, that is to say, the oftener it goes through the rolls, the more likely is it to be honest.

Reference has been made in our columns to the failure of certain ship plates and angles in the North. It is not quite as easy as is desirable to get at the whole truth in these cases. Our inquiries have resulted in the acquisition of information to the effect that such failures have been comparatively numerous, and that the treacherous plates and angles have been in all these recent cases made of basic steel. It will be seen, however, from the letter of our north-eastern correspondent, that such failures are not confined to basic steel. Messrs. Bolckow, Vaughan & Co. have in consequence stated that they will make no more basic plates or angles; and Lloyd's Committee have resolved not to class any ship built of basic steel, and have withdrawn their inspectors from yards where basic steel is used. This line of action must, however, be regarded as only provisional. As soon as the character of basic steel is re-established, it will be accepted by Lloyd's as a material suitable for the construction of ships. For certain purposes it appears to be an excellent metal, but it requires special treatment. Lloyd's will permit boilers to be made of it, but only certain stipulations. Its strength must not exceed about 24 tons on the square inch, and the scantlings must be augmented as compared with acid and Siemens steel standing 30 tons. In fact, it appears to resemble Low Moor or Bowling iron more than anything else. It is worth notice that Lloyd's will not pass any steel which stands more than 30 tons, and when plates exceed 1 in. in thickness the standard is lowered. In all this, we find direct evidence that practical men find it necessary to employ steel with much caution, notwithstanding the admirable qualities which it displays. We understand that Mr. Parker, chief engineer surveyor at Lloyd's, is now conducting a valuable series of experiments with a view to solve the steel problem, and ascertain why plates break. To this end he has subjected steel plates of all kinds to the worst possible treatment—such as heating one corner while the rest is kept cool, making a hot fire on the center of a plate while a hose played on the metal outside the heated circle, and so on—but up to the present he has not succeeded in a single instance in getting a plate to crack.

It cannot be said that any failure of a steel plate is a surprise, because the treacherous character of the material under certain conditions of treatment has long been known. A valuable report to Lloyd's Committee on the steel manufacturing and engineering works of France was prepared by Mr. Parker in 1883. This report is not as well known as it should be. Among other places visited was the Naval Dockyard at Toulon. There they had been long aware of the peculiarities of steel. "The French engineers," says Mr. Parker, "seem to have recognzed to a greater extent than has been done in England the fact that steel requires to be heated with much more care than iron, in order to preserve the normal qualities of the material in a structure; and the plate and angle shops in Toulon Dockyard are fitted with special tools, mostly hydraulic, so that it may not be necessary to hammer or distress the material in any way. These tools are so designed, and the plant is so arranged, that all the work necessary in either plates or angles may be done while the material is at a uniform heat, and before the temperature falls below the acknowledged dangerous limit of dark red. The frames are all heated in gas furnaces on the Gorman system, and by means of ropes, hydraulic capstans, and return pulleys, the frames are turned or drawn to their required curvature in a few seconds of time without any sudden shock or jar; they are then beveled with squeezers, and when completed retain a sufficient heat to anneal them. Again, all garboard strake plates and others involving strong curvatures or sharp changes of form, that in this country are generally bent or flanged by hammers, are at these works bent to form by hydraulic presses, while all shears and punches are also worked by hydraulic power, so that there is a complete absence of jar or jerk in the speed of the tool at the moment when its edge comes in contact with the work punched or sheared, which must necessarily punish the material to a less degree than punches, presses, or shears driven by mechanical gearing. Further, with a view to avoid all useless punishment to the material by punching out curves, circular and curved hydraulic shears are extensively used, and I also observed that for cutting frames, beams, etc., circular and hand saws are used as much as possible. In fact, wherever it is possible to replace hand tool labor, the work of which must be rough and costly, machine tool labor has been introduced, which is much more regular and uniform, and injures the material so little that scarcely any annealing is necessary, and a fractured or cracked plate or angle, such as was so common here a few years ago, is almost unknown at these works." Further on Mr. Parker says: "In view of the valuable information and experience gained during my visit to the Toulon yard, where steel has been so largely employed for the last ten years, I cannot but feel it is a matter for regret that, upon the introduction of steel for ship-building and boiler-making into this country some four years ago, recourse should not have been had by the society's officers to the experience of the French Government officials in the matter. If a visit had then been paid to the dockyards in France, it would, I doubt not, have saved both the committee and executive a great amount of anxiety, inseparable from the society's officers having had to work out for themselves the problems connected with the subject which experience alone could satisfactorily solve."

The Manufacture of Steel Castings.—At the opening meeting for the winter session of the Iron and Steel Works Managers' Institute, held at Dudley on September 12, Mr. R. Smith-Casson in the chair, Mr. B. F. McCallem, of Glasgow, read a paper on "Steel Castings," which developed an interesting discussion upon steel-casting practiee. Mr. MeCallem said that it was thirty years since the first crueible steel eastings were made in Sheffield in the general way, and with one exeeption the method of mauufacture was pretty mueh the same now as at that early date. The improvement was the employment of gas furnaces instead of the old coke holes for melting. Important eeonomies had resulted from this introduction. Where before it required 3 tons of eoke to melt 1 ton of steel, the same thing was now done with 35 ewt. of very poor slaek. Though it was apparently easy to make erucible steel eastings, it was not, in reality, easy to make a true steel—that was to say, to make a metal that eontained only the eorreet proportions of earbon and silicon and mangauese. The only real way to make crueible castings of true steel was to melt the proper proportions of cast steel serap with the proper amounts of silieon and manganese to produee that ehemical eomposition whieh was known to be necessary in best eastings. It was in eonsequeuee of this diffieulty that many makers resorted to the addition of hematite pigs. The Bessemer process was used much more extensively upon the Continent than in this country in the manufacture of eastings. It seemed likely that Mr. Allen's agitator for agitating the steel in the ladle so as to remove the gases, would be taken up largely for open-hearth castings, and open-hearth mild steel, as it had a wonderful effect The Wilsou gas-producer, working in conjunction with the opeu-hearth furnaee, had reeently produced some extremely wonderful results. In some large works steel was, by its aid, being melted from slack, whieh was previously absolutely a waste produet. The method of making open-hearth steel eastings might be varied greatly. The ordinary method generally practieed in this country was a modification of the Terre Noire proeess. The molds employed were only of secondary importanee to the making of the steel itself. Unless the mold was good, no matter how good the steel was, the casting was spoiled. The best composition whieh had been found for molds was that of a large firm in Sheffield, but unfortunately it was rather expensive. A good steel casting ought to eontain about 0.3 per cent. earbon and 0.3 per eent. of silieon, and from 0.6 to 1 per eent of manganese. Such a casting, if free from other impurities, would have a strength of between 30 and 40 tons, and on an 8-ineh speeimen would give an elongation of 20 per eent., or even more It was possible by the Terre Noire process to produce by easting as good a pieee of steel as eould be made by any amouut of rolling and hammeriug.

The ehairmau said that as they had so high an authority as Mr. MeCallem present, Staffordshire men would like to know his opinion upon the open-hearth basic system, in which they were greatly interested.

Mr. MeCallem said that he believed that the basic process would be worked successfully in this eountry in the open-hearth furnaee before it would be in the eonverter. At the Brymbo Works, in Wales, he had seen the basic process worked very sueeessfully in the open-hearth furnace; and he was reeently informed by the manager that he was produeing ingots at the remarkably low sum of 65s. per ton.

The chairman said that some samples which had been sent into Staffordshire from Brymbo for rolling into sheets had behaved admirably. He thought that the Patent Shaft and Axletree Company, at Wednesbury, were at the present moment putting down an open-hearth furnaee on the basic process.

The discussion was continued with considerable vigor by Messrs. H. Fisher (vice-president), James Rigby, J. Tibbs, M. Millard, Walker, W. Yeomans (secretary), and others. Several of these gave it as their experience that the best castings contained the most blowholes, and Mr. McCallem accepted the prououncement with some slight qualification. A vote of thanks to Mr. MeCallem coneluded the proceedings.

RAILWAY NOTES

The United States is now sending abroad about three million dollars' worth of locomotives per annum. This, at an average of ten thousand dollars eaeh, represents about 290 engines.

The method of placing electric lamps in front of locomotive to illuminate the line has been tried ou many lines, but apparently has not found much favor. Recent experiencee in Russia appears to show that financial considerations are not alone uufavorable to the system. On the railway between St. Petersburg and Moseow several locomotives were fitted with eleetrie lamps. For a time they gave great satisfaetion, lighting the way more than a kilometer in frout. But the servants begau to complain of the contrast between the lighted and the unlighted surfaces painfully affectiug the eyes; and doctors ere long reported that there had been several cases of grave injury to the eyes in this way. Hence the lamps were abandoned. The directors have not, however, given up the idea of better illumination for the line, and they now contemplate placing electrie lamps so as to illuminate about one kilometer on either side of the station.

A concession has been granted by the Swiss Government to a firm of electrical engineers at Geueva, for making a railway up Mont Salève, near that eity. The liue will be laid with a central rack, very siuilar to that of the Righi railway, but the toothed pinion on the loeomotive, which gears into it, instead of being driven by steam, will be worked by eleetricity.

According to the *Brèsil*, the total length of the railways of the Brazilian Empire is 8,123 kilos. (5,036 English miles), of which 6132 kilos (3,802 miles are opened for traffic, and 1,991 kilos. (1,234 miles) are still iu coustruction. The railways belonging to the Government have a length of 1,457 kilos. (903 miles), and represent a value of about £11,440,-000 sterling. Of these the Don Pedro is the most important, measuring upwards of 700 kilos. (434 miles), aud representiug a eapital of about £8,000,000 sterling,

ORDNANCE AND NAVAL.

SUMMARY OF EXPERIMENTS MADE BY THE SWISS ARTILLERY, IN 1884.—Two steel Krupp guns of 12 centimeters bore aud hooped, were modified to allow the use of a percussive apparatus for ignitiou, which had been sucessful with an 8 4 centimeter gun; the results in this case being also satisfactory, it was adopted by the committee. The gas-check was of copper, and the committee proposed that two guns should be made of bronze mandriné, in order that the national industry might be enabled to take part in the armament of the country.

The bore of 12 centimeters, being small for a siege piece, it was desired to increase the effect of its shells. Two shells, made at the Gruson Works, were fired iu comparison with ordinary shells and powder charge. The result gave no marked superiority for the Grusou shells, and as their preparation was longer and more complicated, further trials were suspeuded. Experiments were made to determine the influence of eccentricity in projectiles on the accuracy of their range, and the limits to be allowed in their manufacture. As an eccentricity of 2 millimeters had a sensible effect ou the accuracy, the limit was reduced to 1 millimeter.

Experiments with Shrapnel shell, with rear chambers and double-action fuzes for long ranges, resulted in frequent bursts in the bore, due to premature actiou of the striking apparatus of the fuze. This was overcome by shortening the striker; a disk of hardened lead was placed underneath, and a spiral spring above it; at the same time the rear ring of the Shrapnel was modified.

Advantage was taken of these trials to study the effects of Shrapnel. They were charged with hard lead balls of 2 calibers, weighing 15 and 12.5 grains, 395 to 400 balls of 15 grains, and 475 to 480 of 12 grains. At 3,000 meters the Shrapnel with small balls gave one-fourth more hits thau those with large balls. The number of planks touched was also slightly greater with the small balls. At the same range the penetrative force of the small balls seemed to be equal to the larger ones, and the committee adopted balls of 12.5 graius.

The bodies of shells made in Switzerlaud of steeled wrought-iron were generally deformed on impact, and the heads remained unbroken, whilst those of Krupp, of steel, were uninjured and the heads always brokeu.

The carriage was furnished with two shoes specially destined for skidding, but provided with chains to allow the skidding during firing if necessary.

A model ammunition-case, containing five projectiles or ten cartridges, each case for projectiles containing six fuzes and ten percussion tubes, was established, aud each guu allotted two hundred rounds of ammunition and ten extra cartridges. Powder of 16 to 18-millimeter size of grain was used, but pressure being too high, the charge was reduced to 4 25 kilograms. Various samples were tried, wood-powder, octagon and pentagon. Octagon gave the best results. The size of the grains was varied from 15 to 19 millimeters without any inconvenience. A transportable platform, proposed by Lieutenant-Colonel Greesly, was tried, with results which give reason to hope that such platforms will constitute a notable progress in guns of position.

A 12-centimeter mortar, fitted with percussion ignition, was tried with a Greesly transportable platform, and also a field-carriage. The mortar was made from a 10.5 inch gun, shortened by 0.50 millimeter and bored out to 12 centimeters; both platform and carriage were adopted for service use.

A short 15 centimeter bronze gun, which was useless after heavy firing, was re-tubed with bronze to see if it could be rendered serviceable. The projectiles were rotated by copper bands. At first the tube behaved well, but gradually it projected aud separated itself from the gun; a cap was then screwed on the muzzle, but the extension still proceeded, and the re-tubing of bronze guns was abandoned.

A ten-barrel Gatling gun was tried. The barrels were those of Gras rifles. The mechanism worked well up to one thousand two hundred rounds per minute; at known distances the accuracy was good, but at great and unknown distances it was poor. The result of the experiment was the adoption of a six-barrel gun. To avoid premature bursts of shells in the bore, shells were fired with ordinary and a binary powder; also a bursting composition supplied by the Federal Powder Administration. The binary powder was composed of 87 saltpeter and 13 charcoal, aud 80 saltpeter and 20 charcoal The bursts were much weaker than with ordinary powder. The initial velocity of a charge of binary powder was much less than the ordinary, but the pressure was also much lower than usual.

IMPROVED RIFLE FOR THE BRITISH ARMY.—The results of the labors of the committee appointed to provide a new aud improved rifle for the army, which has just been published, show, says the *Times*, that the future weapon of the British army will, as regards most considerations, be far iu advauce of the service arm of any other nation. In the new weapon the Martini breech action has been retained, the alterations being in the barrel and the weight of the projectile, the combination being called the Martini-Enfield. Taking the Martini-Henry as a staudard of comparison, the diameter of the bore has been reduced from 0.46 inches to 0.40 inches, the weight of the new bullet being 384 grains, as compared with the 480-grain bullet of the old rifle. The powder charge, however, of 85 grains remains the same, with the important result that the muzzle velocity of the bullet is increased from 1,315 feet per second to 1,570, thus lowering the trajectory to such an extent that, while the Martini-Henry bullet in traveliug 500 yards rises more thau 8½ feet above the liue of sight, the improved projectile would scarcely go over the head of an infantry man if fired from the ground level. This is a most important consideration, as it minimizes any errors in elevations which might arise either from excitement or miscalculation. The system of grooving adopted is the ratchet, the number of grooves being nine, as against the seven of the Martiui-Henry, although the latter is the largest number employed in any military rifle in the world, while the twist of the bullet has been increased from one turn in 22 inches to one turn in 15 inches, the latter being again in excess of anything which has yet been used for service purposes. In addition to the important reduction in the height of the trajectory, the higher velocity of the bullet and the improved rifling have shown remarkably good target results, the meau deviation of the new bullet being only 0.3 foot, and 0 95 foot at 500 and 1,000 yards respectively, as against 0.55 foot and 1.85 foot for the Martini-Henry. Another very important feature is that the recoil of the new weapon is considerably less than that of the present service arm, which has caused so much adverse comment. Experiments are also being made to provide the new weapon with an attachable magazine, so that in cases of emergeucy the soldier will be able to deliver a rapid fire of several shots without reloading.

BOOK NOTICES

Publications Received.

Report of a Commission appointed to Consider a Geueral System of Drainage for the Valleys of the Mystic, Blackstone and the Charles Rivers. Boston: Wright & Potter.

Report of the Surgeon-General of the United States Navy.

Professional Papers of the Signal Service:

No. XVI.—Tornado Studies for 1884. By John P Finley. Washington: Signal Office.

Papers of the Institution of Civil Engineers:

No. 2081.—The Design and Construction of Railway Rolling Stock in Italy By S. Fadda.

No. 2089.—Experiments on the Measurement of Water over Wiers. By Bryan Donkin, Jun. M. Inst. C. E., and Frank Salter, Assoc. M. Inst. C. E.

A Lecture on Gas and Caloric Engines. By Professor Fleeming Jenkin, LL. D.

Manual of Telegraphy. By W. Williams, Superiutendent Indian Goverument Telegraphs. 327 pp., 8vo (*illustr.*) London: Longmans, Green & Co; New York: D. Van Nostrand. Price $4.20.

The fact that this manual was writteu to order by the Director-General of Telegraphs in India, and that its object is the instruction of the staff, intimates that it should be a practical work. A superficial glance at its contents proves that such is the case, and while the character of the service upon which it is based is such that much of the information is not applicable to the American telegraph systems, it contains sufficient matter of a general character to render it a valuable text-book even in this country. The work is divided into six section. Section A embraces electrical and magnetic definitions; section B, telegraph batteries; section C, signaling instruments; section D, telegraphic circuits; section E, faults in circuits, and their remedy; section F, testing. In an appendix are grouped the laws of currents, of circuits, and of induction; also various formulæ and their solutions, with tables of sines and tangents.

The section devoted to batteries is very complete, and gives not only comprehensive instruction as to their care, but the principles which govern their action. The various types of battery with which our readers are familiar are described, the preference in the Indian service, however, being in favor of the Minotti form, which is essentially the same as the ordinary gravity cell, the sulphate of copper being, however, surmounted with a diaphragm of river sand or sawdust. Each of these materials has its advantages, the choice being governed by circumstances. In the climate of India it might at times be easier to gather sand than saw wood, while if the saw-dust was at hand there would be no occasion for a trip to the Ganges. On account of the time required to bring new cells into working condition, a reserve force is usually kept on hand, from which the zincs are removed (to avoid waste from local action) to be replaced as required.

The Fuller battery has been used to some extent, but is considered as less convenient, and, at the same time, more expensive than the Minotti. The great advantages of the latter are summed up as being due to the constancy of its E.M.F., which remains the same from the time the battery comes into action uutil it is exhausted. It does not depend upon the strength of acid solutions, and the hydrogen generated by the action of the battery, which is the great enemy to constancy when in its free or uncombined state, by virtue of its polarizing effects, is prevented from remaining free by its immediately combining, by chemical affinity, with the sulphate of copper solution, and taking the place of a certain amount of copper which it reduces from the solutiou, depositing it on the copper plate immersed therein, the plate being thus continually supplied with a fresh, bright copper coating, as long as the action of the battery continues.

Thirty-ohm sounders being generally used, four local cells in series are uecessary to the best effect. A standard cell is kept in every office as a unit of E.M.F., being prepared with special care, and used only for testing.

The Siemens polarized relay is universally adopted for departmental use, but it appears not to be wholly satisfactory, excepting for *double-current* working, on account of the small margin for proper adjustment. The efficiency of a relay is tested by its range, ob-by the following rule:

"Adjust the relay with minimum play, with the tongue as far from the metallic stud as regular working will admit of, so that it will work with one cell through a resistance equal to its own; then apply ten cells without any external resistance; the relay should work without readjustment, thus displaying a range of 20, the minimum range a Siemens relay should exhibit."

The Siemeus-Morse souuder is generally used, constructed upon the same principle as the American sounder, but of a less elegant patteru, and with apparently less atteution to its sound-producing qualities. Repeating points appear to be considered as essential to a complete sounder. The armatures are of thin, iron plate, bent cylindrically, the edges uot joining. The following rather elaborate directions arc given for proper adjustment of the spiral spring:

"Adjust the spiral spring by the following process: Work the sounder electrically, and tighten the spring until the magnet is unable to attract the armature; mark the position of the screw on the stem; now loosen the spring until the armature falls on the electro-magnet by its own weight; mark the second position on the screw, then tighten the screw to about midway between the two marks. N. B.—Fix all jam-nuts securely."

Two other forms of sonuders are shown —the Douglas and the Dubirn. The former is similar to those used in this country previous to the advent of the pony sounder. The lever is pivoted in the center like a walking beam, with a sounding post at each end, one for the direct, the other for the back stroke. The Dubirn sounder is designed to utilize the strongest magnetic field. The magnet is placed with its poles downward, and resting on the base, they being extended beyond the helices for a sufficient distance to permit the armature to play between them, it being centered on a pivot midway between the coils. One end of the prolonged armature acts as the sounding part, its excursion being limited by appropriate screws fixed to the base of the instrument.

The portable sounder is a polarized instrument of a pattern which would not find favor with those who are accustomed to the very compact and serviceable outfits produced by American manufacturers, for transportation in the pocket.

Various forms of signaling keys are shown, a description of the discharging key leading up to a very clear explanation of the effects of static induction, upon a well-insulated line, to obviate the effects of which a transmitting device of this character is essential for the purpose of clearing the line between signals. The author says:

"Induction is the main cause which diminishes the speed of signaling; first, by accumulating on the surface of the wire a portion of the current which would otherwise pass on to form signals; the quantity accumulated depending upon the length and surface of the wire, upon its proximity to the earth, and upon the insulating medium which separates it from the earth. For this reason the electro-static capecity of cables is much greater than that of land lines—*i. e.*, they hold a much greater charge. The greater this electro-static capacity, the less the speed, for it causes the first portion of a sent current to be absorbed or accumulated as shown above, and thus it retards the first appearance of the signal at the distant end. Again, at the cessation of the signal the accumulated charge takes an appreciable time to discharge, and consequently each signal is prolonged. Thus, 'charge' *produces retardation, and 'discharge' prolongation.*"

The various common forms of galvanometers and their applications are set forth under the head of testing instruments.

Section C, devoted to magneto-electric instruments, embraces the telephone, and, as naturally associated with it, the microphone transmitter.

A very complete table of electrical symbols for use in diagrams, is given in the space allotted to telegraphic circuits. The open circuit system is generally used in India for the departmental wires, while the closed circuit is used on the State railway lines. The principal duplex circuits are worked on the double current differential system. The bridge and split battery duplex systems are fully described, also Gerrit Smith's battery reverser, and all are more or less used in the Indian service.

For office connections, Hooper's india-rubber-covered wire is given preference over gutta-percha, and it is advised that every joint should be soldered, excepting the terminals at binding screws, which should be kept scrupulously clean.

The development and removal of faults is a most important part of successful telegraphic administration, and in this respect the author has performad a most important duty in pointing out the various ills to which the most perfect electrical system is continually subjected. The electrical and mechanical faults encountered are similar to those which worry the wire chief wherever he may be located.

The last section of the manual gives various methods of testing in all its branches. The peculiar character of the Indian service requires that particular attention be gixeu to the regular testing of the lines, in order that any departure from the normal condition of the circuits may be at once detected and electrically located. The Wheatstone bridge is universally used for this work.

In the appendix are giveu the laws of currents, circuits, electro-magnetism, induction and magnetism, which are convenient of access, and, therefore, add to the value of the book as one of practical utility in the field for which it has been especially prepared.

The general arrangement of the subject matter, with its side notes, marginal titles, and cross references is very commendable, aud no electrician will fail to appreciate the merits of this "Manual of Telegraphy" by merely glancing over its pages.

ELEMENTARY GRAPHIC STATICS, AND THE CONSTRUCTION OF TRUSSED ROOFS; A MANUAL OF THEORY AND PRACTICE. By N. CLIFFORD RICKER. New York: William T. Comstock Price $2.00.

There is a special feature of this work which will commend itself to students of engineering and architecture. It is exhibited in working out to *completion* the problems of trussed roofs. The general problem of determination of strains in the various members is presented with ordinary fullness. But the author does not rest here; he proceeds to find sectional areas, to arrange details, and to exhibit them in suitable diagrams. This last feature is admirably presented.

Ritter's method is employed, as well as the graphic, in determining strains.

A large number of practical examples is given.

SELECT METHODS IN CHEMICAL ANALYSIS. By WILLIAM CROOKES, F. R. S., F. R. C. S. Second edition. London: Longmans, Green & Co.

To practical chemists the mere announcement of a new and enlarged edition of this valuable work is sufficient. The first edition was exhausted some time ago.

The new methods introduced into laboratory practice since the first edition was written, have rendered a thorough revision necessary. Much of it has been rewritten, and an amount of new matter added nearly equal in volume to the original work.

It is now a book of 725 pages. The processes that are commonly known are purposely omitted, the main object of the author having been to bring into notice a number of little-known expedients and precautions which prevent mistakes, insure accuracy, and economize time.

A Treatise on Belts and Pulleys. By J. Howard Cromwell, Ph. B. New York: John Wiley & Sons.

No mechanical engineer will dispute the desirableness of a reliable treatise on Belting. The discordant results obtained by the different rules given by leading authorities are exceedingly confusing.

The work before us shows evidence of careful preparation, and of complete knowledge of the subject.

The large number of examples will prove to be a valuable aid to the young engineer.

A Practical Treatise on Hydraulic Mining in California. By Aug. J. Bowie. New York: D. Van Nostrand.

An estimate of the scope of this work can be well made from the list of topics treated by chapters. They are, in order, as follows:

Chapter I.—The Records of Gold-Washing. II.—History and Development of Placer-Mining in California. III.—General Topography and Geology of California. IV.—Distribution of Gold in Deposits, and Value of Different Strata. V.—Amount of Workable Gravel Remaining in California. VI.—Different Methods of Mining Gold Placers. VII.—Preliminary Investigations. VIII.—Reservoirs and Dams. IX.—Measurement of Flowing Water. X.—Ditches and Flumes. XI.—Pipes and Nozzles. XII.—Various Mechanical Appliances. XIII.—Blasting Gravel Banks. XIV.—Tunnels and Sluices. XV.—Tailings and Dump. XVI.—Washing, or Hydraulicking. XVII.—Distribution of Gold in Sluices. XVIII.—Loss of Gold and Quicksilver. XIX.—Duty of the Miner's Inch. XX—Statistics of Cost of Working and Yield of Gravel.

The printing and illustrations, including maps, are excellent.

MISCELLANEOUS.

The Russian papers say, that, at the request of General Komaroff, Governor of the Transcaspian region, the Minister of War has recognized the urgency of immediately establishing a line of telegraph connecting Merv with Askabad. This line would pass by Annow, Babadoorma, Bougatchik, Artchigan, and Sarakhs. Its length will be 500 versts, and the expense about 100,000 roubles.

The monthly report of Mr. William Crookes, Dr. William Odling, and Dr. C. Meymott Tidy shows that the character of the water supplied to the metropolis (London) during the past month has been in every respect excellent. The mean ratio of brown to blue tint of color in the Thames-derived water was found to be as 11.4:20; while the mean proportion of organic carbon was .128 part in 100,000 parts of the water, with a maximum in any one sample examined of .148 part; this maximum of organic carbon corresponding to just over a quarter of a grain of organic matter per gallon.

Hellhoffite.—Comparative trials have been made at St. Petersburg respecting the explosive effects of ordinary gunpowder, nitroglycerine, and a new explosive known as hellhoffite. The latter, which has been recently invented by Hellhoff and Gruson, is a solution of a nitrated organic combination (naphthalene, phenol, benzine, etc.) in fuming nitric acid. In preparing the hellhoffite tried in the experiments, binitrobenzene, a solid, inexplosive, and badly burning substance, was used. At the first trial, glass bottles of 20 cubic centimeters contents each were filled with 25 grammes of the respective explosive substances and corked down. A tube filled with fulminate of mercury was passed through the corks, a slow-match being attached to the outer end of the tube for the purpose of ignition. Each of the bottles thus prepared was placed on a truncated cone of lead, the upper diameter of which was 3.5, its lower 4.5, and its height 6 centimeters. The cone itself stood on a cast-iron plate 2.5 centimeters thick. The deformation of the leaden cone by the action of the explosives could consequently be taken as a measure of their respective destructive power. The explosion of the gunpowder, as was anticipated, caused no change. By the explosion of the nitro-glycerine, the cone was compressed about a quarter of its height; its surface had assumed the appearance of a well-worn hammer; the diameter of the surface had been increased to 5.5 centimeters. The explosion of the hellhoffite caused much greater changes. The surface of the cone was completely torn; pieces 5 centimeters long and 2 centimeters thick were torn off, and thrown about for several paces; only half of the cone was still a compact but entirely defaced mass. At the second experiment, bottles (of 25 grammes each) filled with the various explosive substances were let into corresponding cavities bored into the face of fir blocks of similar dimensions. In exploding the gunpowder, the block was torn into four pieces, as if split with a hatchet; the several pieces were thrown about for 18, 12, 11, and 10 paces. In exploding the nitro-glycerine, the block was split into several pieces. The upper portion of the block, as far as the bottle was let into it, was torn off perpendicularly in the direction of the fiber in such a manner that a smooth cut was formed. The explosion of the hellhoffite likewise tore the portion of the block surrounding the bottle perpendicularly in the direction of the fiber, and splintered the remainder of the block into a large number of thin fibers. The following experiments were also made with hellhoffite alone. A slow-match was passed through the tube in the cork without fulminate of mercury as far as the surface of the hellhoffite in the glass bottle; no explosion followed on igniting the slow-match. A quantity of hellhoffite poured into a bowl could not be exploded by a lighted match. Finally, a few drops of hellhoffite were poured on an anvil, and exposed to heavy blows with a hammer, and no explosion followed. The hellhoffite, consequently, possesses the following advantages: (1) In igniting it with fulminate of mercury, it acts more powerfully than nitro-glycerine. (2) It may be stored and transported with perfect safety as regards concussion, as it cannot be exploded either by a blow or a shock, nor by an open flame. On the other hand, it has the following disadvantages: (1) Hellhoffite is a liquid. (2) The fuming nitric acid contained in hellhoffite is of such a volatile nature that it can be stored only in perfectly closed vessels. (3) Hellhoffite is rendered completely inexplosive by being mixed with water, and can consequently not be employed for works under water. It would, therefore, be injuriously affected by exposure to damp, and, moreover, there are no records of its behavior under extremes of temperature. Without some experiments in this direction, in our opinion, all the rest is comparatively valueless.

Effect of Encasing Wood with Iron.—It was always expected, since first wooden ships were clothed with armor plates, that they would speedily decay, and this anticipation has been abundantly realized. The only excuse for the armor-plating of the *Lord Clyde*, *Lord Warden*, *Ocean*, *Prince Consort*, *Caledonia*, *Zealous*, *Royal Oak*, *Repulse*, *Royal Sovereign*, *Favorite* and *Research*, was the fact that the vessels were already built or building, and were of no use at all unless so protected. When once those ships of the line were completed that happened to be on the stocks when ironclads were proved to be an absolute necessity, no other wooden ironclads were laid down in this country, but iron ships took their place. But in France wooden ironclads continued to be built until within the last eight years, and it is this fact which has doubtless induced the French Admiralty to lay down so many iron and steel ironclads since that time. It is the closely-fitted wooden backing on the outside and flanking on the inside which entirely prevents air from getting at the unseasoned oak timber of the frames, and this causes the juices of the timber to ferment, and so induces the growth of the peculiar fungus known as dry-rot. An examination of our wooden ironclad fleet a few years ago resulted in their being almost entirely condemned, and now we find the admiralty are turning them into money by selling them to the ship breakers. The *Royal Sovereign*—the ship in which Captain Coles' turrets were first tested—also the *Zealous* and *Favorite*, have just been sold for this purpose, and others will doubtless speedily follow. While vessels of less than twenty-five years old are thus being broken up on account of rottenness, it is interesting to notice the number of two and three-decked wooden ships—some of them nearly a hundred years, and none of them less than thirty or forty years old—which still survive in ordinary use at Portsmouth, Devonport, and Sheerness. These were built of seasoned timber before the age of hurry set in.

A Mechanical Air Purifier.—An apparatus for purifying air from dust, germs, or other impurities, has recently been designed by M. Windhausen. It consists of two horizontal concentric cylinders placed in connection with a fan. The fan and cylinders are fixed upon and turn with the same shaft, and the whole is enclosed in a casing. The cylinders are closed at the ends with the exception of a hole permitting the passage of the air drawn in by the fan. As the air passes through the concentric space between the drums, it is caused to rotate with them by means of feathers running longitudinally on the inside of the outer cylinder. The shaft which carries the whole arrangement is hollow, and serves to convey water which is allowed to escape therefrom inside the drums by means of small holes, which project it in the form of fine spray against the inside of the inner cylinder. This cylinder is also perforated, and the water again escapes from it and is projected against the inside of the outer cylinder, over which it spreads as a thin coating. The motions of the air and water are as nearly as possible in opposite directions. The water, after it has been sufficiently exposed to the air, is allowed to escape, and is drawn off by means of a siphon. The same arrangement may be modified for treating smoke or gases.

Telegraphs in China.—We learn from *Nature* that telegraphs are extending with extraordinary rapidity over Southern China. At the present moment, Pekin, in the far north, is connected by a direct line through Canton with Lungchow, on the frontier of Tonquin, the extension from Canton to the latter place having been made during the recent war purely for military purposes. We have thus one great line stretching through the Chinese Empire from north to south, and at the present moment an important line is being constructed along the southern borders of China, through the provinces of Kwantung, Kwangsi, and Yunnan. Starting from Nanking, in Kwansi, where it joins the Canton-Lungchow line, it will extend for nearly 600 miles to Nung-lik, in South Yunnan, running for half the distance along the Yukiang, the name of the Canton River in its upper course. The work is being carried out by the Chinese themselves, with the assistance of one European, and it is stated that during the recent war the Canton authorities equipped a complete field telegraph staff, the members of which were so thoroughly trained that they have been able to put up 35 miles of line in a single day for war purposes. Telegraphs have now secured a firm footing in China, and their extension over the whole country is a matter of time only.

The *Organe des Mines* seriously states that a company is about to establish large works for making rails from paper near St. Petersburg. The paper is subjected to great pressure, and it is said that the material is extremely durable and can be produced at one-third the cost of steel rails.

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VAN NOSTRAND'S
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THE FLOW OF WATER OVER SUBMERGED WEIRS.

By EDWARD SAWYER.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

I.

Under the title "The Flow Through Submerged Outlets," there appeared in the June number of this Magazine, a translation of an article by M. Alfred Salles, published in the "Memoires of the Bureau des Ponts et Chausées" for 1884,—which will grievously mislead those who take it as embodying the present state of knowledge on this subject.

The writer attributes to M. Mary, under date of 1860, the following formula, for the delivery through partly submerged sluices,

$$Q = mLH'\sqrt{2g \times (H - H' + h)}$$

in which L is the length of the sluice, H is the height of the water on the up-stream side above the sill of the sluice, H′ is the height of the surface on the down-stream side above the same level, h is the height due to the velocity of the current on the up-stream side, and m is a coefficient not experimentally determined, but assumed to be about 0.8.

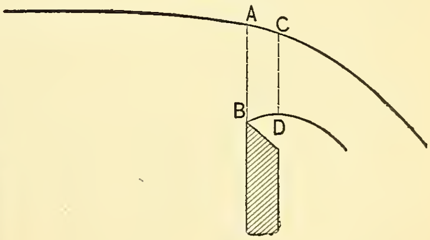
M. Salles then substitutes in this formula, numerical data obtained at a dam across the river Garonne, at Toulouse, and deduces 0.82 as an approximate value for m, "agreeing remarkably with M. Mary's anticipation."

A brief examination will show that this agreement is purely accidental.

This formula makes the value of Q depend directly upon that of H′, or the height of the backwater,—it takes H′ as the depth of the stream. It is obvious that if the channel below the dam were deepened so as to lower the backwater, other data remaining the same, Q would be increased; but this formula makes it decrease. Drawing the backwater down to the crest of the weir, in this way Q would increase while the formula would decrease it to nothing.

This absurdity results from confounding the case of flow through a *sluice* with the radically different one of flow over a weir. For the latter case, the formula in question misrepresents both factors of the discharge—the depth of stream, as above shown—and also its velocity. In the case of free discharge over a weir, it is universally admitted, and indeed is easily proved, that the velocity of discharge, at AB or CD (Fig. 1), increases

Fig. 1



from the surface downwards. In flow over a submerged weir, the velocity must also increase, similarly, down to the *back-water* surface; but there is no reason to believe that it increases down through the remainder of the depth to the crest of the weir, where the discharge is made against still or slow-moving water. Hence it is all wrong to assume, by using this formula, that the mean velocity for the whole depth flowing over a submerged weir can be represented by

$$\sqrt{2g(\mathrm{H}-\mathrm{H}'+h)}$$

(or any constant fraction thereof), as a general expression, where $\mathrm{H}' \div \mathrm{H}$ can have any value less than unity.

This unfortunate confusion appears to have originated with Lesbros, before 1850, and in consequence of it, his writings and those of his followers have obscured the subject, instead of elucidating it, as a brief résumé of the progress of knowledge in regard to it will show.

We will continue to use the same symbols as heretofore, but will eliminate L, by taking q=the discharge for a unit of length of weir=$\mathrm{Q} \div \mathrm{L}$; and will substitute F for $\mathrm{H}-\mathrm{H}'$, representing both the height of the free section and the fall, where that is most convenient.

Dubuat had a good understanding of this subject more than 100 years ago. In his "Principes d'Hydraulique," t. I., §§ 141–147, editions of 1786 and 1816, he elaborates the general theory, dividing the stream into a free section acting like an unobstructed weir with velocity increasing from the surface downwards, and a submerged section acting like a rectangular orifice of the height H′ and under the head

$$(\mathrm{F}+h).$$

He also describes the dam or weir with which he made a single experiment for obtaining a coefficient of discharge to be used in his formula.

D'Aubuisson, in his undated treatise on "Hydraulics," published probably before Lesbros' "Memoire," quotes Dubuat, to this effect, adopts this division of the stream, and proposes coefficients deduced from his own experiments. His corrections for velocity of approach are not well managed, however, and we may simplify the matter by eliminating them for the present; *i.e.*, taking the case of discharge from still water. His formula hen becomes, for English feet,

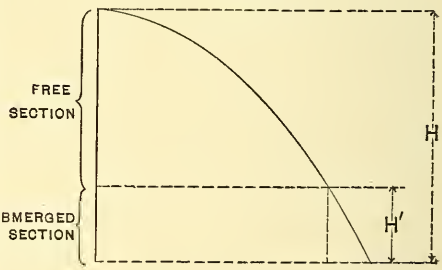
$$q = 3.48\ \mathrm{F}^{1.5} + 4.98\ \mathrm{H}'\sqrt{\mathrm{F}}.$$

According to the best modern experiments, as will appear further on, an expression of this form will represent the discharge very closely, *i. e.*, the coefficients for it are nearly constant, but their mean values are about 3.33 and 4.59 respectively, for a weir having a vertical sharp-edged face of sufficient height to produce complete contraction. Hence D'Aubuisson's formula gives results which may be from $4\frac{1}{2}$ to 9 per cent. too large for standard weirs, but are not far wrong for many practical cases where the contraction is somewhat less.

Other eminent experts, before 1850, adopted this general theory, with some variations in the coefficients and in form of statement. Among these were Eytelwein, in his "Mechanik fester Körper und Hydraulik," published in 1800, 1822 and 1842; and Weisbach, in his "Mechanics," published in 1846.

These two writers assume the coefficient of discharge of the free section at two-thirds that of the submerged section, as indicated by the parabola of ve-

Fig. 2



locities (Fig. 2), which reduces the formula to

$$q = n\left(\tfrac{2}{3}\mathrm{F}^{1.5} + \mathrm{H}'\sqrt{\mathrm{F}}\right)$$

or

$$q = c\sqrt{\mathrm{F}}\,(\mathrm{H} + 0.5\mathrm{H}')$$

Lesbros' experiments were made in 1828–1834, mainly with reference to free discharge through orifices, and the section of his report relative to "Dépenses des Déversoirs Incomplets ou en Partie Noyés" appears to be a sort of by-product.

He brought the water to some of his orifices through a long, rectangular open channel, supplied through a square-edged aperture, of the same width and depth, in the vertical side of a reservoir, with its bottom in the same level plane with the bottom of the channel and aperture (Fig. 3), and his discussion is based upon observations of the conditions of flow through this aperture.

In beginning his examination of the subject, Lesbros refers to Dubuat's "Principes, t. I. §§. 141–147, but instead of taking the theory there set forth, he turns to t. II. §. 413, etc., where Dubuat describes the small weir (0.11 m. high and 0.47 m. long), with which he made four experiments with free discharge, and one with the flow obstructed by *back-water*. For the case of free discharge Dubuat concludes that q varies with $(H+h)^{1.5}$. From this, Lesbros appears to have evolved the formula for submerged weirs,

$$q=m(H+h)\sqrt{2g(F+h)},$$

which he says—falsely so far as I see—that Dubuat *indicates.* Having thus ignored Dubuat's whole theory as stated in §§. 141–147, and set up in his name a a formula utterly inconsistent with it, he undertakes to demolish the latter by saying that if it expresses the true law of the phenomena, it is evidently suitable for *déversoirs* formed at the entrances of canals like those with which he experimented, *i. e.*, with apertures starting from a level floor, because the escaping stream is partly submerged in both cases, whereas he finds, by putting the data from his aperture experiments into it, that the resulting values for the coefficient vary *wildly*, from 4. to 0.287.

It seems that he reaches this result by a process which Dubuat probably would have condemned, that is, by taking H′ at the highest place in the channel below the aperture, sometimes at the lower end, see Fig. 3; for he announces as a result of his study of the subject, that instead of this, it ought to be taken at the lowest place, in the depression at the foot of the fall. Taking it in this way, and neglecting h, which was unimportant in his experiments, he represents the discharge by the expression $H\sqrt{F}$, with a coefficient varying with the relative values of H and H′, but entirely independent of their absolute values, or the *scale* of the experiment.

But his apparatus was radically different from a *weir*, and manifestly unfit for showing the laws of flow over one.

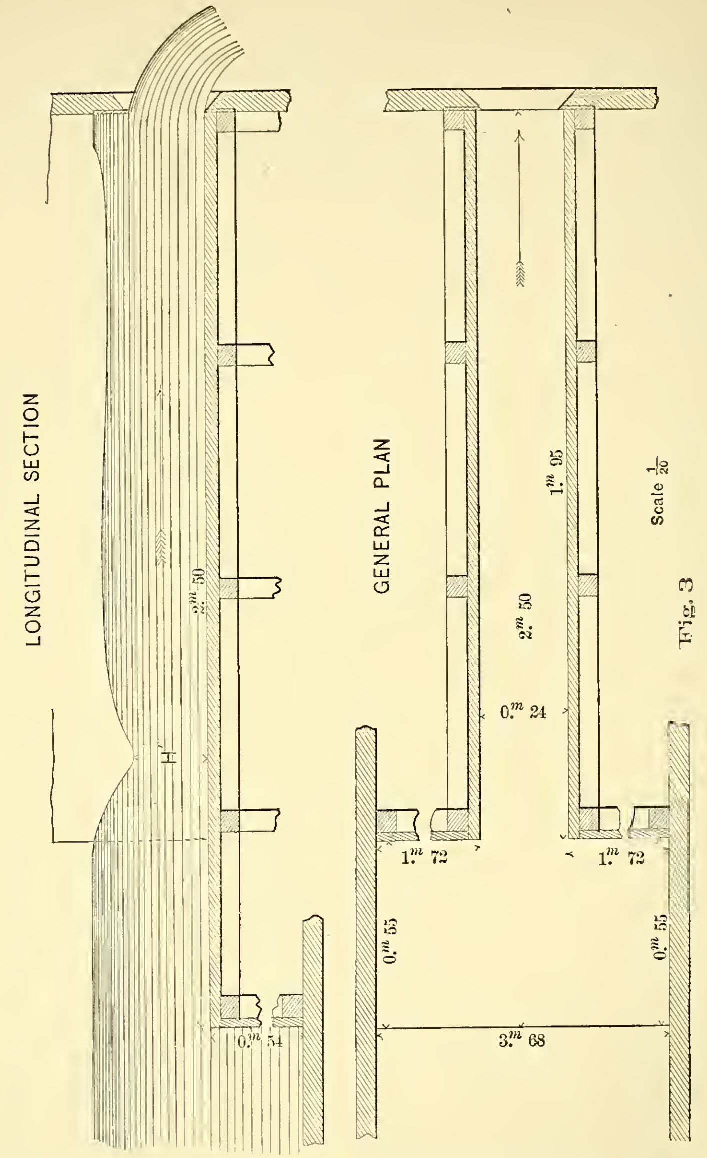
One characteristic of a weir is that it produces bottom contraction; and contractions are suppressed, or else the narrowing of the stream caused by them is rebated directly from the length of the weir. With this apparatus there was no bottom contraction, but instead thereof, two end contractions, with falls varying from .0027 m. to 135 m.

In fact, without these end contractions there would have been no sudden fall here, only the slopes appropriate to flows in a uniform channel.

Neither was there any deepening of the channel down-stream from the aperture; hence the water, instead of falling into a deep channel of escape, had to flow over the level floor. Thus, the depth down-stream from the aperture affected q, not merely by limiting the fall, but also as being the depth of a section through which all the water had to pass after leaving the aperture. H′ cannot be reduced to 0, because no water can flow in a stream of no depth, though Lesbros exterpolates coefficients out to this impossible extreme.

Probably Lesbros, in trying to simplify the expression, reasoned that all the water finally passes under the accelerating action of the net head F (in reaching the section of minimum depth H′), hence that this fall should be taken as acting on the whole stream, but apparently he was aware that the resistance here was less than that against flow into still water, though he left the effect of this and other neglected factors to be covered by the variations in the coefficient. In fact the discharge was made against water moving in the same direction towards an orifice opening into the air. With the water in the reservoir maintained at any given height H, the two components into which it is divided, fall of surface and depth at H′, are affected by the more or less resistance to the escape through the channel and orifice. As this resistance diminishes, the depth in the channel diminishes and the velocity there increases. The resulting diminution of resistance to flow at H′ allows the velocity there to increase faster than $\sqrt{F+h}$. But the actual velocity of the stream at this place is difficult of determination, in consequence of the varying narrowing of the effective area by the end contractions,

Fig. 3



and the varying curvature of the surface crosswise of the stream.

If this curvature makes the mean depth less than H′, the mean fall is greater than H−H′, but Lesbros ignores this effect.

Thus the mean depth will sometimes vary from H′, the effective width will vary, sometimes widely, from the full width of the channel, and the velocity will not bear a constant relation to

$$\sqrt{F+h}.$$

For these reasons, Mary's formula is unsuitable for this case, though it cannot be run into the absurdity of supposing discharge without depth. If we attempt to apply it to Lesbros's data by assuming streams of the full width of the channel and of the depth H′, we make merely mathematical transformations, taking cross-sections reduced in the ratios of H′ to H and coefficients increased in the same ratios, respectively. But it is interesting to note the results of such transformations, as exhibited below:

	From Lesbros' Experiments.					Exterpolated by Lesbros.			
Values of H′÷H	.95	.85	.75	.65	.56	.50	.30	.10	0
L.'s coefficient	.522	.512	.502	.492	.481	.474	.444	.409	.390
M.'s "	.55	.60	.67	.76	.86	.95	1.48	4.09	Infinity.

Lesbros' exterpolations evidently run wild.

The actual velocity at the smallest section was apparently materially above 86 per cent. of that due to the fall, where that coefficient appears, as the cross section was probably materially reduced by end contractions.

This formula is also worse than Lesbros' in the case of a submerged weir, where H′ can vary independently of H down to 0 or minus, and where it involves the absurdity of diminishing q to 0, as the backwater resistance disappears.

Mary's supposed teachings should not be criticised in the absence of his own statement. The hypothesis most creditable to him is that he did not intend his formula for submerged weirs, but for some form of sluice different from Lesbros' apparatus.

M. Salles computes the flow in the Garonne with his data, and Lesbros' formula and coefficient, and finds the result far too small. If he had corrected for velocity of approach, as Lesbros doubtless intended, the discrepancy would have been much less, though still large.

But the dam was nowhere near high enough to produce complete contraction. According to the data given, the depth up stream from the dam could not have exceeded $6\frac{3}{4}$ meters, while the surface was about 6 m. above the crest; hence the dam was only about $\frac{3}{4}$ m. high. Whatever its form of cross-section, it would be but a slight obstruction to a stream nearly 9 times as deep. Hence, the discharge was much greater than it would be over a normal weir producing full contraction. If this dam produced a surface fall of about 1 m., as stated, we must infer that its height on the down-stream side was much more than $\frac{3}{4}$ m., that the channel was much lower there than on the up-stream side.

It is evident that French writers of the last half century have made an unfortunate departure backwards in neglecting the teachings of Dubuat and D'Aubuisson and following the line here exposed.

II.

In Germany, painstaking but unsuccessful investigations of the subject were made by Bornemann, between 1866 and 1872. He attempts to represent his results by various complicated formulas, but the coefficients which he deduces differ so widely as to show conclusively that one or more of the principal factors is not properly represented in these formulas.

But it is highly improbable that his facts are all wrong. There is a strong presumption that his statements of heights and quantities discharged are mainly correct. Let us examine them with the aid of graphic representation:

For this purpose, I plot the values of H as ordinates, and those of H′ as abscissas, in a rectangular system, the common origin representing the crest of the weir. At each point whose co-ordinates represent the heights observed in an experiment, conceive a perpendicular erected from the plain of the paper, and of a height representing the corresponding value of q. Erecting a vertical in this way for each experiment, the upper ends will determine points in a curved surface representing the values of q for all values of H and H′ within the *field* or range of the data. Values of q for intermediate points may be interpolated, and curved lines may be drawn in the surface for constant values of q, with any degree of minuteness which the exactness of the data and the scale of the drawing will justify.

Fig. 4 gives part of Bornemann's results translated into English feet, and shown in this way, by broken lines, with the heights of weirs W, and the values of q written in them. It also shows the true co-ordinates for four of these values of q with normal weirs, by full lines, deduced from American experiments of the highest authority.

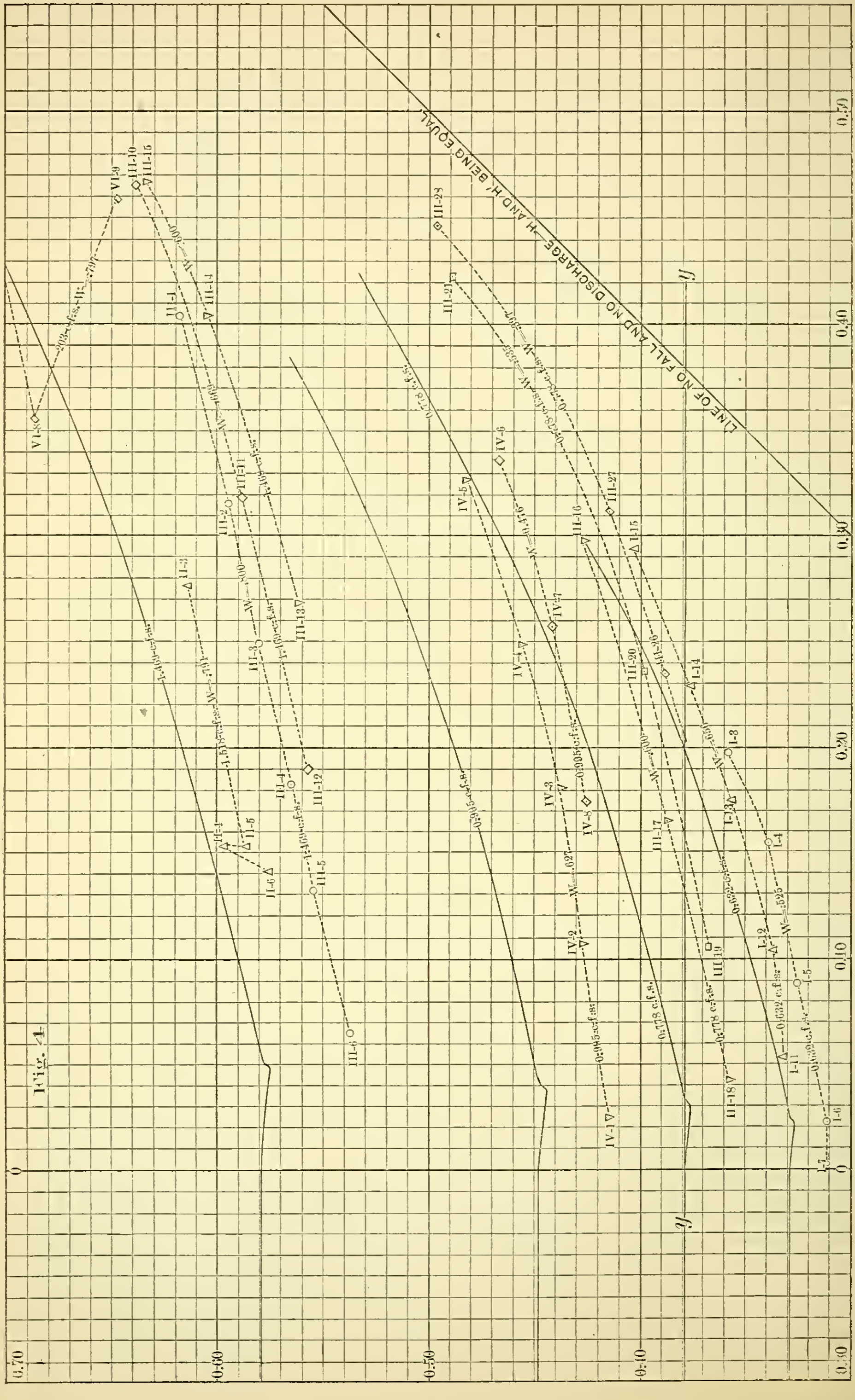

LINE OF NO FALL AND NO DISCHARGE—H AND H, BEING EQUAL
0.70
0.60
0.50
0.40
0.30
0.50
0.40
0.30
0.20
0.10
0
y
y

Fig. 4.

To the left of the origin the values of H′ are minus, or downward from the crest of the weir, and cease to affect the discharge materially. In this part of the field, then, the lines of constant discharge become straight.

In looking at this diagram, we are forcibly reminded of the obvious but important fact that a formula may disagree with some of the results of experiment without being wrong—that the latter are inexact. It is evident that vi. 9, and two of the group ii. 4, ii. 5 and ii. 6 are materially *out*, perhaps from clerical or typographical errors. Several other points also appear to be slightly out, judging by their incongruity with their neighbors, which is a better test than comparing them with distant points by the aid of a theory which is itself the object of the investigation.

It will be seen that the discharges for given values of H and H′ were all considerably larger than those for a normal weir, as shown by the full lines.

It is obvious at a glance that the height of the weir W was an important factor, and that the variations of q for identical values of H and H′ were caused by the variations of W; also that the excesses over the discharges for a normal weir were probably due to the insufficient heights of the weirs.

An essential characteristic of a weir is that it causes the stream to contract vertically, requiring increase of velocity and fall to produce this increase. It is obvious that a barrier just beginning to rise across the bottom of a channel will just begin to deflect and contract the stream; as it rises higher this effect will increase, but not indefinitely. For Bornemann's values of H, it is probable that the full effect of contraction, or very nearly the whole, is reached when $W=2\frac{1}{2}H$. Up to the point of complete contraction, raising the weir increases H, or else diminishes the discharge, by increasing the contraction, also by increasing the depth and thus diminishing the velocity of approach.

Doubtless the discharge of a submerged section is also increased by velocity of departure, as suggested by Fteley and Stearns, where the stream is not much deflected after passing the crest; hence discharges against water having a considerable horizontal component of motion, instead of against that which has little or no motion down stream.

After full contraction is developed, further raising of the weir increases H only by changing these velocities, and to a small extent.

When $W=2\frac{1}{2}H$ the crest is above the backwater and we have free discharge into air, but submergence can, of course, be produced, and the value of H′ can be varied at will, by obstructing the flow on the down-stream side.

The simplest way to test Bornemann's experiments, in this regard, seems to be as follows:

Take a line of experiments with q constant, say .778*cfs*, and take H constant at .3793=H for this q with normal weir, free discharge and no velocity of approach ($V_a=0$). Make a diagram (Fig. 5) in which the abscissas represent heights of weir W, or, rather, the depths of the bottom of the channel below a permanent crest, beginning with O and increasing to the left. Let the ordinate at the origin represent the constant value of H=.3793, and the ordinates to the left of the origin represent the decreasing values of H′ necessitated by the increasing values of W, ascertained by drawing the horizontal line *yy*, Fig. 4, at the height H=.3793, and noting the values of H′ at which this line intersects the curves of constant discharge ($q=.778$). Plotting these values as ordinates at the corresponding values of W, we find a line indicating the diminutions in the values of H′, and hence the increments of fall required to balance the increasing contraction from increase of W and the slight falling off in velocity due to increase of depth with increase of W.

Assuming that the full effect of contraction would have been developed at some stage between W=.80 and W=1.10, the corresponding depths would have varied from 1.18 to 1.48, and the values of V_a from .66 to 0.53; and I estimate that the velocities of approach for this part of the diagram would have been sufficent to balance the effect of backwater up to the curve *zz*. Wherever complete contraction occurs, the line limiting the heights of H′ will descend to and unite with the line *zz*. The data is insufficient for fixing this point exactly, but apparently the lines cannot be far apart to the left of $W=.95=2\frac{1}{2}\times.3793$, and perhaps they meet a little to the right of this.

The ordinates to the curve show approximately the values of H′, or heights of backwater) which balance the effects of velocity of approach and defect of contraction, as the depth below the crest varies from 0 to 0.95±. Or we may regard the complements of these ordinates (.3793−H′) as the falls which are needful, in addition to the velocities of approach, to produce the discharge.

Velocity of approach, V_a, is an inseparable element in the operation, varying inversely with the depth. Where W=0, there is no contraction, hence no fall is required to produce acceleration therefor, H′=H, and V_a accounts for the whole effect. As W increases, V_a diminishes and F increases, tending toward the limit, $V_a'=0$, F the sole *motive*.

Some idea of the relative importance of the velocity component may be gained from the following considerations. At the origin,

where

W=0, depth=.3793, V_a=2.05, h=.065;

where

W=.95, depth=1.33, V_a=.585, h=.0053.

We find from Fig. 4 that when W=.60, H′=.135. From the American experiments we know that, for a normal weir without velocity of approach and H and H′ as here, q=.71 instead of .778, difference, .068. The velocity of approach probably accounts for nearly half of this, leaving the other half, more or less, for the increase by defect of contraction at this place.

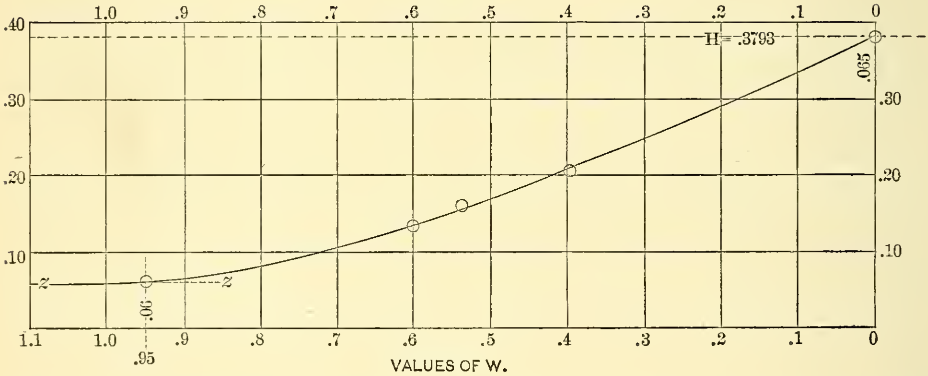
Similar investigations of Bornemann's data with other values of q and H, give similar results, but with some irregularities.

The conclusion seems irresistible that Bornemann's weirs were too low, and that their varying deficiencies in this respect will account for the variations not otherwise accounted for or reasonably chargeable to error.

This introduction of one unnecessary variable, W, throws his experiments into the class of intermediate cases—they have little or no value for the general case—for ascertaining the laws of flow over a normal weir.

It would now be possible to collate Bornemann's results together and apply corrections fixing the most probable values. Such changes as would thus be introduced into the data would, of course, affect the foregoing investigation and diagrams, but would not materially change the general results. I take the figures as they stand, and give the results as approximations, not as the closest that could be deduced from the data with unlimited labor.

Fig. 5



VALUES OF W.

III.

American Experiments.

Data incomparably better and fuller than any other known to the writer have been furnished by

a. Six experiments made by James B. Francis in 1848.—"Lowell Hydraulic Experiments," p. 99.

b. Twenty-two experiments made by Messrs. Fteley & Stearns in 1877.—

"Proceedings of the American Society of Civil Engineers" for 1883, and

c. About fifty experiments by Francis in 1883.—Proceedings of same society for 1884.

Fteley & Stearns, of course, did not have the benefit of the latter series of experiments, in their discussion. Taking the formula

$$q=c\sqrt{F}\,(H+0.5\,H') \qquad (1)$$

or

$$q=c\sqrt{F}\,(F+1.5\,H') \qquad (1')$$

they find values of c varying from 3.372 to 3.089, for varying values of $H'\div H$. The later experiments indicate that it also varies slightly with the absolute value of H—the maximum variation in whole range of the experiments being about $2\frac{1}{2}$ per cent.

Francis finds that the coefficients become nearly constant at the values 3.33 and 1.381, so that the formula

$$q=3.33\,\sqrt{F}\,(F+1.381\,H') \qquad (2)$$

or

$$q=3.33\,F^{1.5}+4.5988\,\sqrt{F}\,H' \qquad (2')$$

follows the data with a good approach to accuracy; the discrepancies being partly due to small errors in the data, but not wholly.

It is known that at certain stages of backwater, in the vicinity of $H'=0.08\,H$, its presence increases the discharge slightly, instead of decreasing it, and the formulas (2) (2′) do not take account of this effect. It appears also that as $H'\div H$ increases, the second coefficient slowly diminishes to 1.35 ± and then slowly increases again; though the values of q found by taking the medium value 1.381, differ but slightly from the truth; not over 1 or 2 per cent. at the maximum.

In these experiments, the minimum value of $W\div H$ (with free discharge) appears to have been 2.71. The values of H varied from about 4 in. to about 2 ft. 4 in., and the values of H′ from O up to $\frac{1}{2}$ H and in some cases to .7 H or more; and the field is well covered for practical purposes, up to and considerably above these limits.

But a further study of it may have some scientific interest, and will, at least, show where more experiments are desirable for perfecting the theory.

In all cases, the water was delivered to the channels in which the weirs were established, through fixed orifices, under large heads, so that small accidental variations of fall produced but slight changes in the efflux. These small variations of fall were closely noted and their effects on the discharges were allowed for in the usual way. The discharge for some particular fall was computed from values of H when the backwater was below its range of effect. Then keeping the discharge as nearly constant as practicable, the backwater was raised step by step, and the corresponding values of H′ and H were noted.

The greatest mean velocity of approach appears to have been about 1.31 ft. per second.

Keeping the dischange constant and varying H′ and H, as above, the effect of the velocity of approach remains very nearly constant, and hence no correction was made for it, as I understand. If the velocity of approach had been made indefinitely small by deepening the channel, the quantity, with free discharge and any observed value of H, would have been as reckoned; and it is assumed that with this actual discharge maintained without velocity of approach, the increasing series of values of H′ and H would also have been found identical with those actually observed. I estimate that this cannot make an error of one-tenth of one per cent., hence is unimportant.

By plotting the data, with co-ordinates of the full size, in the same way as described for Bornemann's experiments, we bring the results within easy grasp and greatly facilitate the examination and weighting of them.

It is needful, however, to eliminate the small accidental variations in the quantity discharged. For this purpose, we may observe that all lines with positive co-ordinates and making angles of 45° with the axes, are lines of constant fall. According to formula (2′) all vertical planes erected on such diagonals intersect the curved surface which represents q, in straight lines having rates of rise equal to $4.5988\times\sqrt{F}$. In fact, these intersections are not exactly straight lines, the coefficient not being quite constant; but for these small adjustments, the constant 4.6 is near enough.

Taking, for instance, the series of experiments where q was taken at the average value of 7.202, we find in Francis's experiment No. 43, $q=7.174$ or 0.028 less. F = 1.254. $.028 \div 4.6 \sqrt{1.254}=$ .0054. Hence q would be increased from 7.174 to 7.202 by increasing H and H′ .0054 each and the co-ordinates so found will fix a point in the curve of $q=7.202$.

Where H′ is minus, the adjustment is made on the value of H only.

Having thus adjusted all the points at which q differed materially from the average of its series and plotted the results with all the others, it is useful to write at each point the values for the variable coefficients deduced from the experiment there represented.

On comparing either formula with the data as thus exhibited, it is apparent that there are some small outstanding variations of coefficients which the formulas do not take into account, as stated in the first part of this section. They are complicated, of course, with the small inaccuracies of the data. The latter may be eliminated approximately by the laborius empirical process of drawing an estimated mean line through each series of points and adjusting to regularity. With the large quantities corresponding to the upper part of the diagram, we may expect inaccuracies of .01 or .02 ft. in the values of H and H′, and correct curves of formulas may vary from some of the points to that extent. The surface fixed by these curves should be *regular*, or free from irrational crooks, in all directions. We may test it by means of series differences or otherwise, and the crooks so found should be eliminated by altering the curves, with due regard to the equality and distribution of the plus and minus variations from the data. Series for this purpose may be taken on lines running across the field in any direction; but lines with judiciously selected values of variables are better than others.

In this way we test and determine the correction for each point mainly by its congruity with the points in its vicinity, their influence diminishing as their distance increases, instead of attempting to give distant points equal weights by the aid of any theory as to the relations of q to H and H′.

A study of a diagram so worked up develops several interesting relations and hypotheses, more or less clearly; but further experiments of extreme precision are needed for perfecting the whole theory.

For practical purposes, however, a well-adjusted diagram of this kind, will be substantially cleared from probable errors of data and from the corrections for the small variations of the coefficients.

With a line of constant discharge for each 0.10 *cfs* in the upper part of the diagram and for each 0.05 *cfs* in the lower part, it is easy to interpolate by estimation to one-tenth of these quantities respectively, hence, to read off the value of q for any values of H and H′ within the limits of the diagram, with substantially all the precision which our experimental data will justify, and more than will ordinarily be attained in practice in the ascertainment of H and H′ and in allowing for velocity of approach. That is, the results will be more exact than would ordinarily be obtained in any other way and about as good as it is possible to obtain with existing data.

Carrying Coals to Newcastle.—Carrying coals to Newcastle has hitherto been held to be an absurd proceeding; but it will no longer be treated in that contemptuous fashion if what we hear from Staffordshire is correct. It is stated that a new feature of competition from Spain with English iron-masters is just now making its appearance in Staffordshire. It is the introduction into that market of Spanish hematite pig iron. This is pretty much the first time that Spanish hematites have been offered in this country, the Spaniards having been previously content to supply English iron-masters with their rich iron ores from the Bilbao and other mines, wherewith to make hematites in this country, and heavy shipments of these ores are imported weekly into South Wales, the North of England, and some other of the English centers. The Spanish hematite iron which is just now being offered, is imported from Somorrostro, and a richness is claimed for it which, it is alleged, is in advance of that possessed by the ordinary English hematite pig irons. The analysis of the new pig is stated to be as follows: Silicon, 0.2; manganese, 0.85; sulphur, 0.029; phosphorus, 0.038; pure iron, 97.083. The agents who are introducing the foreign iron are, we are informed, authorized to sell at a low price, and they will make an effort to get a footing upon the English iron markets. An evident moral is to be drawn from the above. If pig iron can be imported at a profit into England from abroad, why not, it may be asked, some day coal?

THE PROPOSED ABOLITION OF THE ASTRONOMICAL DAY AND ITS BEARING ON PROBLEMS OF NAVIGATION.

By Professor STIMSON J. BROWN, U.S.N.

Proceedings of the United States Naval Institute of Annapolis, Md.

With the growth of commerce and the vast extension of telegraph and railroad systems, the necessity of a reform in the usual methods of time-reckoning has made itself forcibly felt. This has expressed itself in various attemps to adopt systems of standard time which should embrace as wide an extent of longitude as possible, and at the same time vary but little from the local time of any place using one of these systems. Thus, it was a comparatively easy matter for Great Britain, in 1848, and Sweden, in 1879, to adopt as legal standard times, the mean solar day beginning at midnight of the meridian of their respective Government observatories. The solution of the problem in the United States and Canada has been more difficult, on account of their wide extent in longitude. Yet, at a railway time convention in 1883, a system was adopted, and shortly after carried into execution, which system embodies all the essential principles necessary for uniformity in the chronology and time-reckoning of the ordinary affairs of life. It will be remembered that this plan divided the two countries into districts by meridians one hour of time apart; that the division into districts was so made that the central meridian of each is an integral number of hours west of the Greenwich meridian; and that from the central meridian of each district the standard time of the whole district is to be reckoned.

In Continental Europe, with railroad, telegraph and postal routes extending through different countries separated by purely artificial boundaries, the inconvenience has been even greater than in the United States; but national pride and jealousy have proved serious obstacles to systematic reform. Chief among these has been the necessity, in any thorough reform, of the selection of an initial meridian which would be universally recognized.

Out of the discussion which these attempts have involved, has developed the idea of a universal day. Such a day would begin, for the whole world, at a given instant of time at the initial meridian; but by this scheme the various epochs of the day would begin one hour later for each hour of longitude to the west, and there has been no serious attempt to adapt it to the practical affairs of everyday life. The railway-time system of the United States is only a simple modification of this idea. With standards of time carried out for the whole world on this system, the process of finding the universal date and time would be a very simple one, and the variation of local date and time reduced to a simple rule.

The necessity of a universal prime meridian, met in all the proposed plans for securing uniformity in time-reckoning, has always been urged by sea-faring men for a different purpose. It is not necessary to more than refer to the utility and convenience to navigators of the adoption of a universal zero point from which to reckon longitude. The need of this has been a prominent factor in the success of the movement toward uniformity in the methods of time reckoning.

The various commercial and scientific societies of Europe, in which these questions have been discussed, have from time to time suggested the United States as the most favorable nation, for obvious reasons, for taking the initiatory steps in calling up an international conference for selecting this prime meridian. The subject, in this country, had been so generally discussed, and the utility of the proposed reforms so generally recognized, that Congress, in 1882, passed an Act authorizing the President to call an international conference for the purpose of carrying the project into execution. After the arrangement of the necessary diplomatic preliminaries, the Conference met in Washington in October, 1884. All its acts are of special interest to nautical men, one of them proposing no less radical a reform than the abolition of the astronomical day.

The second resolution reads as follows: "That the Conference proposes to the Governments here represented the adoption of the meridian passing through the center of the transit instrument at the Greenwich Observatory, as the initial meridian for longitude." The vote of San Domingo was the only negative vote; the delegates from France and Brazil abstained from voting.

The third resolution was, "That from this meridian, longitude shall be counted in two directions up to 180 degrees, east longitude being plus and west longitude minus." This reversal of the uniform custom of navigators in regard to the sign for the application of longitude arose from its application in reducing universal time to local time; it is of little importance to navigators, as the precepts for its application to local or Greenwich time are too simple to cause any confusion as to the meaning of the resolution.

The third and fourth resolutions were in regard to the universal day, defining it as beginning at the moment of mean midnight of the initial meridian, coinciding with the beginning of the civil day and date of that meridian, the hours to be counted successively from 0 to 24.

In the sixth resolution, "The Conference expresses the hope that as soon as may be practicable the astronomical and nautical day will be arranged everywhere to begin at mean midnight."

This resolution, though anticipated, has met with strong opposition from the majority of eminent astronomers, particularly Europe. It is not difficult to see why they should oppose any innovation of the long-established and natural method of counting astronomical time. No one has so forcibly presented the objections from an astronomical point of view as Professor Newcomb; I therefore quote at length his letter to Commodore Franklin, protesting against the adoption of the new system, January 1, 1885:

"The first of these recommendations proposes a change in the method of counting astronomical time which has come down to us from antiquity. The practice of taking noon as the moment from which to count the hours originated with Ptolemy. This practice is not, as some distinguished members of the Conference seem to have supposed, based solely upon the inconvenience to the astronomer of changing his day at midnight, but was adopted because it was the most natural method of measuring solar time. At any one place solar time is measured by the motion of the sun and is expressed by the sun's hour angle. By uniform custom, hour angles are reckoned from the meridian of the place, and thus by a natural process the solar day is counted from the moment the sun passes over the meridian of the place, or over the standard meridian. For the same reason the sidereal day is counted from the moment the vernal equinox passes over the meridian of the place, and thus the two times correspond to the relation between the sun and the equinox.

"It would appear that the Conference adopted the recommendation under the impression that the change would involve nothing more than the current method of reckoning time among astronomers, and could therefore be adopted without serious inconvenience. . . .

"A change in the system of reckoning astronomical time is not merely a change of habit, such as a new method of counting time in civil life would be, but a change in the whole literature and teaching of the subject. The existing system permeates all the ephemerides and observations which fill the library of the astronomer. All his text-books, his teachings, his tables, his formulæ, and his habits of calculation are based on this system. To change this system will involve a change in many of the precepts and methods laid down in his text-books.

"But this would only be the beginning of the confusion. Astronomical observations and ephemerides are made and printed not only for the present time, but for future generations and centuries. If the system is changed as proposed, the astronomers of future generations who refer to these publications must bear this change in mind, in order not to misinterpret the data before them. The case will be yet worse if the change is not made by all the ephemerides and astronomers at the same time epoch. It will then be necessary for the astronomers o the twentieth century, using observations and ephemerides of the present, to know, remember, and have constantly in mind a certain date different in each case at which the change was adopted. . . .

"It is difficult to present to others than astronomers who have used the published observations, the confusion, embarrassments and mistakes that will arise to their successors from the change. The case can be illustrated by saying that it is of the same kind—though in less degree than—the confusion that would arise to readers and historians in the future, if we should reverse or alter the meaning of a number of words in our language, with a result that the reader would not know what the words meant unless he noticed at what date the book was printed. . . .

"The change will affect the navigator as well as the astronomer. Whether the navigator should commence his day at noon or midnight, it is certain that he must determine his latitude from the sun at noon. The present system of counting the day from noon enables him to do this in a simple manner, since he changes his own noon into the astronomical period by the simple addition or subtraction of his longitude. To introduce any change whatever in the habits of computation of uneducated men is a slow and difficult matter, and is the more difficult when a complex system is to be substituted for a simple one. I am decidedly of the opinion that any attempt to change the form of printing astronomical ephemerides for the use of our navigators would meet with objections so strong that they could not be practically overcome."

The objections from an authority of such eminence in astronomical matters seems to be shared by the majority of astronomers in Europe; but it should be noticed that these objections are raised only in so far as they affect astronomers and their work. At the last meeting of the Astronomische Gesellschaft (at Geneva, in August, 1885), the discussion of the 6th resolution of the Conference was limited by the emphatic declaration of the President to its consideration from a purely astronomical standpoint; thus limited, although no formal resolution of the society was adopted, a large majority expressed themselves as opposed to the change. Those speaking in favor of the change were, however, among the most eminent astronomers of the society; they recognized the difficulties it would entail to astronomers, but were willing to make the sacrifice for the sake of gaining uniformity in methods of reckoning time; to these may be added Professor J. C. Adams, of Cambridge; Professor Christie, Astronomer Royal of Great Britain, as well as Professor Oppolzer, of Germany. The last named proposes to give practical effect to his views by adopting the new reckoning in an extensive list of solar and lunar eclipses which he is now preparing for publication. Professor Adams pointed out in the proceedings of the Conference that there were noted exceptions even to the universality of the old method; such, for instance as Delambre's Tables of the Sun, Burg's, Burkhart's, and Damoiseau's Tables of the Moon; Bouvard's Tables of Jupiter, Saturn and Uranus; in all of which mean midnight is used as the epoch of the tables. Also La Place, in his "Mecanique Celeste," uses Paris mean midnight as the origin of the astronomical day.

American astronomers have been as unanimous in favor of the change as those of Europe against it. Shortly after the Conference, Commodore Franklin, Superintendent of the Naval Obervatory, sent out a circular letter soliciting expressions of opinion on the subject. So far as I have been able to learn, with the exception of Professor Newcomb's letter above quoted, favorable answers were returned. Most of them, however, and this may be said of all who favor the change, advise waiting until a certain date can be fixed upon by international agreement. Nautical almanacs are published, or in course of publication, up to 1890, and the change could not well be carried into effect before that date. Professor Tietjen, who directs the publication of the *Berliner Jahrbuch*, has said that, in his opinion, such a change would not find place there before 1900. Thus it will be seen that astronomers are about evenly divided as to numbers if not as to ability.

It may be mentioned here that the change was formally adopted at the Greenwich Observatory, January 1, 1885, thus initiating the confusion liable to arise from the selection of different dates for the inauguration of the change, the dangers of which are so forcibly pointed out in Professor Newcomb's letter. At the same time the adoption of this action by so prominent an observatory will tend to compel its ultimate adoption by all.

An examination of the opinions of astronomers will lead, I think, to the conclusion that those astronomers who are chiefly engaged in combining and discussing the vast mass of observations from various sources and widely different times, are generally opposed to any change; while those who perform the practical work of making the observations are as unanimous in its favor. To the latter the change would be a simple one, and give rise to little or no inconvenience. To the former the inconveniences introduced and the liability to error would be felt for a long time. It would seem, though, that they to whom the change might prove burdensome, are fitted by their skill, education and training to avoid the mistakes to which there would be liability.

However, it is not the purpose of this article to discuss the opinions of astronomers, or the effect such change would have on purely astronomical work, but rather to call the attention of naval officers and nautical men generally to the effect it would have on the various problems of the navigator; whether it will introduce, as Professor Newcomb says, a complicated system for a simple one, and, consequently, cause liability to errors, or whether it will be a gain in simplicity by avoiding the use of the two dates aboard ship, one for the log and one for the navigator. These are questions which the education and experience of naval officers ought to fit them to discuss. If the discussion leads to a general expression of opinion by intelligent navigators that the change will introduce more simple and direct methods, then the opinions of the uneducated navigator, whose opposition Professor Newcomb predicts, ought not to stand in the way of its adoption. It is to be expected that they would object to any change in their habits of computation, no matter for what ultimate gain; if, on the contrary, the change introduces methods which, although simple to educated men, would perplex and confuse those of little mathematical education, these objections ought to be respected.

At the first glance it would seem to be self-evident that the use of two dates to represent the same instant of time, and the necessity of reducing the civil date of the ship's log to the astronomical date of the Nautical Almanac, is not a simple system, and would be attended by liability to error. I think it will be found that navigators of considerable experience have at times made mistakes in taking data from the almanac, by confusing the two dates. Yet, on the other hand, in nearly all the methods of finding a ship's position at sea, or the chronometer error by observations on shore, the hour angle of a celestial object from the upper meridian is either directly the result of the computation, or is used in the computation for finding some other required quantity. Under the proposed system the hour angles obtained would have to be reduced to the lower meridian, or from the lower to the upper meridian to be used in the computation. Whether this reduction would be attended by as much inconvenience and liability to error as the simple process of changing the date, ought to be discussed. It should be considered what changes in the precepts and rules contained in all works on nautical astronomy, and in the tables employed, will be necessary to make perfectly plain to the thumb-rule class the transition to the new system.

A general idea of this can be obtained by an examination in detail of the various problems of navigation. By far the most frequently used are those involving observations of the sun: 1st, for latitude by meridian altitude; 2d, for longitude by time sight; 3d, for latitude by off-meridian sights; and 4th, for latitude by circum-meridian altitudes. Observations of the moon, planets and stars, for latitude or longitude, though comparatively infrequent, are generally used only on those times when observation of the sun has been impossible and it is important to find an approximate position of the ship. On such an occasion, a serious error due to the changed methods might be disastrous. It will first be noted as a factor in every problem that the Greenwich date and time would be indicated simply by the application of the longitude to local date and time; that the latter is the civil date and time, except that the P. M. hour must be increased by twelve hours. Under the present method, the civil date and time are first reduced to local astronomical date and time, by adding twelve hours to the A. M. time, and decreasing the number indicating the civil date by a unit, for forenoon time; for P. M. time the date and time are shown immediately by the civil date and time. The change substitutes the simple rule that there is but one date, and that is the civil or local date.

The tabulated data for the first problem, finding the latitude by a meridian altitude of the sun, are given on page I. of the Nautical Almanac, for Greenwich apparent noon; for obvious reasons, this could be advantageously left as it is, the navigator bearing in mind only the fact of the coincidence of civil and astronomical time. The use of page I. is confined almost to this one problem, and the data when used for other purposes only required approximately. In all other cases, and perhaps in this, the data would be tabulated, in accordance with the new system, for Greenwich mean midnight, or for times reckoned from that instant.

In the second problem, the data would be taken from page II. of the Nautical Almanac and corrected for the G. M. time of observation; the hour angle would be found from the usual tables; the only change would be in the addition of twelve hours to the hour angle resulting from an afternoon sight, instead of that from the forenoon sight.

In the third problem, the hour angle of the sun would be required for the computation; this would be found for an A. M. sight, by subtracting the L. A. time from twelve hours; for a P. M. sight, by subtracting twelve hours from the L. A. time. Here again a simple change in an old precept is made.

The hour angle required in the fourth problem, to reduce the altitude of the sun to meridian altitude, would be found as before, by comparing the Greenwich time of observation as shown by the chronometer with the Greenwich mean time of apparent noon. The only difference being that noon occurs at 12 hours instead of at 0 hours, as before.

So far as these problems are concerned the changes are very simple; in those involving observations of the moon, planets or stars, the effects of the changes are not so obvious, involving, as they do, changes of hour angle into sidereal time, and the reverse. In time sights of these bodies, the data required from the Nautical Almanac would be found and corrected for the Greenwich mean time of the observation, as before. The resulting hour angle simply designated (in hours, minutes and seconds) as east or west of the meridian, would be reduced to the lower meridian by subtracting it from or adding it to 12 hours, according as the observation was east or west of the meridian. This hour angle would be converted into local sidereal time and this again into local mean time, by the usual formula.

In all other problems in which the hour angle of these bodies is required for the computation, it would be found, as before, by subtracting the right ascension of the body from the local sidereal time; this hour angle, though, is referred to the lower meridian; it would be reduced to upper meridian by subtracting it from 12 hours for an observation east of the meridian, by subtracting 12 hours from the hour angle for an observation west of the meridian.

The following precepts would be found sufficient to make plain the use of the Nautical Almanac and the necessary tables with the origin of the astronomical day at midnight:

I. The astronomical day begins at mean midnight, and coincides with the civil day and date; the hours are counted successively, beginning at midnight from 0 to 24.

II. All data of the Almanac are given for the astronomical date and time as defined in I.

III. The local astronomical time is given directly by the civil time in the forenoon; in the afternoon, by the addition of 12 hours to the civil time.

IV. All hour angles resulting from observations of the moon, planets or stars, expressed simply as east or west hour angle, are to be reduced to the lower meridian by subtracting the east hour angle from 12 hours, or by adding 12 hours to the west hour angle.

V. Hour angles thus reduced are to be reduced to local sidereal time by the addition to the hour angle of the right ascension of the body for the Greenwich mean time of the observation.

VI. Local sidereal time is reduced to local mean time, as follows: Subtract from the local sidereal time the right ascension of the mean sun for Greenwich mean midnight of the given date plus the correction for the Greenwich mean time; or subtract from the local sidereal time the right ascension of the mean sun for Greenwich mean midnight corrected for longitude; the resulting sidereal interval is corrected as usual by Table II. of the American Ephemeris, or any other table for converting sidereal into mean time interval.

VII. To reduce local mean time to sidereal time, add to the local mean time the right ascension of the mean sun for Greenwich mean midnight of the given date, corrected for the Greenwich mean time.

VIII. To find the hour angle of a body, for use in computation:

1. For tne sun: for a forenoon sight, subtract the local apparent time of observation from 12 hours; for an afternoon sight, subtract the local apparent time from 12 hours.

2. For the moon, planet or star: find the local sidereal time by VII.: from the local sidereal time subtract the right ascension of the body observed for the Greenwich mean time of the observation; the result is the hour angle from the lower meridian. For an observation east of the meridian, subtract this result from 12 hours; for an observation west of the meridian, subtract 12 hours from the result.

It will be readily seen that they affect the whole literature of nautical astronomy. The changes, taken by themselves, are not difficult to understand; yet anyone using the existing text-books on the subject would be obliged to make in them the changes necessary to adapt them to the different origin of reckoning time; a difficult thing for one to whom the subject is a new one. Or, studying them as they now are, he would be obliged to change important precepts which had been learned with difficulty. To rightly estimate how difficult this would be, one must look at it not from the standpoint of the skilled navigator, but as one to whom the subject of nautical astronomy is full of perplexities.

It is easy for one who has a thorough knowledge of the theory of the subject to make the necessary precepts for himself, or to readily see the bearing of new ones given for the use of tables under the new system; but would the majority of navigators come under this head?

It may seem trivial and unnecessary to examine in detail all the problems of nautical astronomy to see what effect general changes would produce; yet it serves to show that the meridian of the place is the natural origin to which are referred the various quantities used in or derived from the computations; by this the problems are simple and direct. It is for this reason that the nautical or astronomical day is the most convenient; that it is made to begin at noon. To change its beginning to midnight is only an apparent gain in uniformity. It is not designed for the purpose of chronology, and is not so used; and there is no reason why it should coincide with the day used for that purpose. The civil day is used aboard ship in all cases when it is most suitable; the nautical day only by the navigator in those problems of navigation where it simplifies astronomical calculation. As such, its retention would not conflict with the purposes of those who aim to secure uniformity for chronological and commercial purposes.

Le Yacht of December 19th, 1885, gives a capital summary of the effects of the firing from the Hercules at Portsmouth against the Moncrieff gun. It remarks that the quick-firing and machine guns firing at about 1,300 yards' range for ten minutes made sufficiently close shooting and such hits that it could scarcely be decided whether the gun would have been disabled or not by them. The shrapnel had fired at about 3,000 yards with less effect, and the common shell with still less. None of the dummy detachment were struck. The results were considered strongly in favor of the Moncrieff system. There is an account of the operations of the French fleet in the capture of the Pescadores Islands. The geographical position of the Pescadores is declared to be admirable, better, in fact, than that of Hong-Kong, and the port of Makung, and well suited to the requirements of the French fleet in the Chinese waters.

ON THE RELATIVE CORROSION OF IRON AND STEEL.

By WILLIAM PARKER, Chief Engineer-Surveyor of Lloyd's Register, London.

A few weeks ago I had the honor to read a paper before a kindred society—the Institution of Naval Architects—on some peculiarities in the behavior of steel, which had come under my own observation, bearing chiefly upon its qualities of uniformity and ductility. On the present occasion I desire to deal with an entirely different branch of the subject, namely, that relating to the power of steel to withstand corrosion, chiefly in connection with marine boilers and in comparison with iron.

When mild steel was first introduced, a few years ago, two questions were prominently discussed: one was its reliability as a constructive material, the other was its durability so far as corrosion, under different conditions of employment, was concerned. The only experience which had been obtained with steel in these directions, up to that time, was with a different quality of the material to that used in the present day, and it was sufficiently various and contradictory to give rise to much disagreement and no little speculation. This, although it retarded the introduction of mild steel, was in one sense an advantage, for it gave rise to extensive experiments which, while they could not entirely set these questions a rest, at least tended to throw light on the peculiarities of the metal, and hence lead to its more intelligent manipulation and preservation.

Among the earliest important attempts to deal with the question of corrosion in recent years were the investigations of the late Admiralty Boiler Committee. It is not too much to say that the investigations of that committee were eagerly looked for by all interested in the subject. The results have been for some time before the public, and have given rise to much discussion. On the surface they appeared decidedly unfavorable to steel, and deductions have been made from them which are, to my mind, open to exception. I have therefore thought that a brief analysis of the methods adopted in conducting the experiments would be not only interesting, but that, in view of the prominence accorded to those experiments, it is almost called for at the present time.

It will be seen, in looking into the experiments conducted by this committee, that in most of the vertical tubes in which the plates were experimented upon in boiling water (with or without air) there was a copper plate present, and in many instances the different iron and steel plates were held in position by brass or copper rods, while no precautions had been taken to insulate them. Moreover, all the steel plates had been fixed above the iron ones, and as the temperature was greater in the upper than in the lower parts of the tubes, it might have been expected, other things being equal, that the steel would corrode faster than the iron. Fig. 1 shows one of these tubes with the disks attached.

It could not be said, therefore, that the results of the investigations of the boiler committee had settled the question of corrosion, and we were induced to look again to the limited experience that existed, and to the comprehensive experiments made about forty years ago, by Mr. Robert Mallet for the British Association. These experiments were on chilled and "green-sand" cast irons, made by hot and cold blast, or hammered and rolled cast, blister, shear, and spring steels; hammered and rolled wrought iron, including Swedish, Lowmoor, and many ordinary sorts of iron, down to puddled bars.

The value of Mr. Mallet's paper on these experiments is diminished by the fact that the scale was left on the cast iron in nearly every case, while it is not definitely stated whether it was removed from the wrought iron; but the experiments are nevertheless extremely interesting, and a feature worth notice in them is the appended analyses and densities of some of the materials experimented upon. It may be mentioned that the square plates experimented upon were fixed with their four corners to wooden frames and placed in wooden boxes. The complete results of the experiments will be found in the "Transactions of the British Association" for the years 1838, 1840, and 1843. The losses by corrosion are given in these tables in grains per square inch, per 732 days, and they can be readily compared with the results of some experiments to be described hereafter, as they are nearly a hundred times greater than if they had been given on the scale I have adopted, which is in pounds per square foot per annum.

Comparing the mean losses given by Mr. Mallet of the ordinary sorts of iron with those of Swedish and Lowmoor iron, a difference in favor of the last two is observed when exposed to river-water and to fresh sea-water, while the latter irons compare unfavorably with the common irons when subject to the atmosphere or to what he calls "foul sea-water." The specific gravity stands in close relation to the amount of corrosion, it being found that in all the different classes of material, whether chilled or "green" cast iron, steel, or wrought iron, the heaviest metal of each description lost less than the lightest one. The analyses, of which a full description is appended to the report, show also beyond doubt that the greater the amount of combined carbon (found by combustion), and perhaps silicon, the less was the corrosion. The manganese, which was present in very small quantities, has played such a subordinate part that its effect cannot be traced. These are, so far as I can gather, the principal conclusions to be drawn from Mr. Mallet's paper, although he was of opinion that the finer the quality of the iron the less it will corrode.

These conclusions, if correct, would be an important addition to our knowledge, but they scarcely accord with the results of experience, and, as I have pointed out, we are at once met by the difficulty that in the case of Mr. Mallet's experiments we are left in doubt whether the scale was removed or not; and in the case of the boiler committee, we are left in doubt how far the want of insulation may have affected the results; and there is the further difficulty in comparing the two sets of experiments, that those of Mr. Mallet were only made in low temperatures and those of the boiler committee in high ones.

It was shortly after the issue of the first report of the boiler committee that

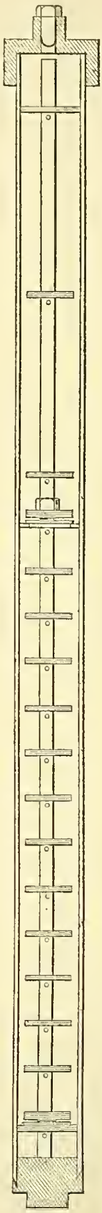


Fig. 1

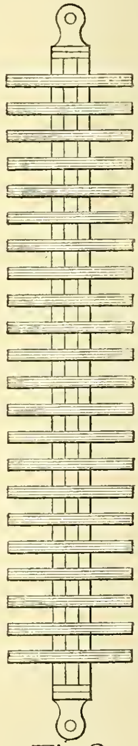


Fig. 2

I commenced to investigate the subject for the committee of Lloyd's Register of Shipping, and I then endeavored to arrange the series of experiments I am about to describe, so as to avoid as far as possible the sources of error indicated above, and to show the effect of the absence as well as the presence of scale.

In the first place, I obtained twelve disks, $4\frac{1}{2}$ inches diameter and about $\frac{1}{4}$ inch thick, from each of the following manufacturers:

Common iron from the Parkhead Forge Company, Glasgow.

Common iron from Skerne Iron Works Company, Darlington.

Best quality iron from Lowmoor Iron Company.

Best quality iron from Bowling Iron Company.

Best quality iron from Farnley Iron Company.

Best quality iron from Messrs. Taylor Brothers, Leeds.

Best quality iron from Leeds Forge Company.

Mild steel from Landore Steel Company.

Mild steel from Bolton Iron and Steel Company.

Mild steel from Messrs. John Brown & Co.

Mild steel from Steel Company of Scotland.

Six of the disks from each maker were turned bright entirely to remove all scale, and the other six were turned round the edge only, so as to damage the scale as little as possible. Each disk was carefully weighed to $\frac{1}{50000}$th part of its own weight at the Royal Naval College, Greenwich, through the kindness of Professor Reinold. They were divided into six series, each containing twenty-two disks, one black and one bright, from each of the above-named works, and were fixed together, as shown in Fig. 2, by means of an iron rod which had been covered by a glass tube, the plates being separated from each other by means of glass ferrules about $\frac{3}{4}$-inch long and 1 inch diameter, thus, so far as possible, insulating each disk and preventing galvanic action being set up between them. I may mention that one of these sets of disks as insulated was immersed in sea-water, and it was found that by completing the circuit between any two of them a galvanic current was set up, the bright Lowmoor plate being electro-positive to the whole of the other plates; and as it is impossible that the energy represented by the galvanic current could be generated without oxidation or corrosion of the metal, the necessity of thoroughly insulating the disks is evident.

One series (A) was suspended on the roof of a building in the city of London, exposed to the action of the atmosphere, from the 13th February, 1879, to 13th May, 1880, or 455 days.

Another set (B) was securely fixed under water to the pier at Brighton from 24th February, 1879, to 7th May, 1880, or 437 days.

A third series (C) was so secured to the engine-room floors of a ship trading to the east as to be freely exposed to the action of the bilge water from 9th June, 1879, to 6th February, 1880, or 240 days.

The remaining three sets (D, E, and F) were hung up in the wide waterspaces between the tubes of marine boilers in such a manner that they could not swing about, and were always about twelve inches below the water-line. These boilers were each in different vessels, employed in different trades, and subjected to entirely different treatment. The vessels containing series D belonging to the British India Company, was employed in the East Indian trade; zinc was used in these boilers, and they were blown off as seldom as possible. The immersion lasted from the 15th February, 1879, to 6th June, 1879, and from 14th June, 1879, to 16th February, 1880, or 361 days.

In the steamer containing set E, owned by the Peninsular and Oriental Company, and engaged in the China trade, no zinc was used in the boilers, which were blown out at each terminal port and run up afresh with salt water. This series was exposed from the 15th February, 1879, to 6th June, 1879, and from 12th June, 1879, to 13th November, 1879, or 264 days.

The remaining series (F) was exposed in the boiler of a steam-collier, running between Newcastle and London from the 23d May, 1879, to the 23d April, 1880, or 336 days.

No zinc was used in this boiler, and the water was taken from a point in the Tyne where it is probable that the refuse from one of the local chemical works acidulates it considerably. The boiler was emptied once in ten weeks, and steam was kept up for four days out of every five.

After the completion of the exposure the scale and rust were removed as carefully as possible by scraping and brushing the disks with a file card, and each one was again weighed at the Greenwich College with the same nicety as in the first place, and the results follow in a tabulated form.

Bright Disks.

Table I. gives the loss of metal per square foot per annum. This was obtained by dividing the total loss of weight of each disk by its exact area (about $\frac{1}{4}$ of a square foot) and by the total period during which each set was exposed, which includes the time that the boilers were empty or not in use.

Table II. was compiled from Table I. by dividing each of the losses in the different columns by the loss of the respective Lowmoor plates, so that the different sorts of iron and steel can be readily compared.

Looking at Table II., under the heading of "Cold Water," and in the third column, which gives the mean values of the relative losses in the sea and bilge water, it will be seen that there are but two metals—Bowling iron and Messrs. Brown's steel—which corroded more than Lowmoor iron; and, although the average loss of steel is a little greater than that of iron, the difference is so slight that for practical purposes it is safe to assume that bright steel, exposed to the sea or bilge water, corrodes no faster than bright iron, especially than the better qualities of iron. When exposed to the atmosphere, although there is no great difference between the common and the better sorts of iron, the steel appears to have lost considerably more than either Lowmoor or any other iron; and the same is the case with those disks exposed to the action of boiler-water with or without zinc. But although the absolute losses of both iron and steel is least, the relative difference of losses of steel and iron is greatest in the boiler in which zinc is used. Here the steel has lost about 50 per cent. more than Lowmoor iron, and Lowmoor iron 50 per cent. more than Bowling iron, or 40 per cent. more than the average of the other irons. On referring to Table I., column 4, it will be seen that the average losses per square foot are very small, and that the greatest loss of steel (Messrs. Brown's) in the boiler with zinc was less than the smallest loss of iron (Bowling) in the air, and far less than the Bowling iron in the other two boilers.

Returning to Table II., we observe in column 9 that the steel, with one exception, has on an average corroded only about 14 per cent. more than Lowmoor iron, which has always been considered as amongst the most suitable for the internal portions of boilers, and which has corroded about 20 per cent. more than the ordinary irons. So that, although the present experiments confirm the prevailing impressions that bright, mild steel does corrode faster than iron, when we get from the condition of a marine boiler to cold sea and bilge water, the difference is not so great as to establish the matter beyond question. I have here specimens of the steel and iron disks out of the boiler containing zinc. You will observe that the surface of these specimens is only a little rough, and that the corrosion is very uniform, which is the case with all the bright plates exposed in this boiler.

The plates exposed to the atmosphere are slightly rougher, but also uniform, while those suspended in the boiler of the Peninsular and Oriental Company's vessels are roughly and more irregularly corroded. It is not a little surprising to find that it is only amongst the disks exposed in this boiler, and those exposed to the bilge water that any deep pitting has taken place. There were four cases, of which I produce two specimens (Nos. 3 and 4), which are very distinctly pitted. These were Farnley iron and Messrs. Brown's steel. The one contains a pit mark about $\frac{1}{16}$th of an inch deep, and the others pit marks not quite so deep. The plates submerged in the sea were irregularly attacked and rather patchy. Those exposed to the bilge water looked still worse, the black plates now and again containing pit marks and the fibers of the iron in many cases being distinctly visible. (See samples Nos. 5 and 6.)

The plates exposed in the boiler of the coasting vessel had accidentally come adrift, and the insulation was thus destroyed within the last ten weeks of their immersion, and they do not show the action of the water so distinctly as in the other cases. No pitting has occurred, but the structure of the iron has in one or two instances been conspicuously brought out. (See sample No. 7.) The Lowmoor disk placed in this boiler also showed very marked projections, one of which, about two square inches in area, contained a thin red scale of what proved by analysis to be copper.

TABLE I.—ABSOLUTE LOSS OF IRON AND STEEL IN POUNDS PER SQUARE FOOT OF BRIGHT SURFACE PER ANNUM.

	Coldwater.		Atmosphere, London.	Boilers.		
	Sea. B.	Bilge. C.	A.	Zinc in boiler. D.	Collier boiler F.	P. & O. boiler. E.
Parkhead common iron	.190	.415	.156	058	.566	.195
Skerne common iron	.137	.556	.151	.062	.485	.203
Common Iron mean	163	485	.153	.060	.525	.199
Leeds forge best iron	.168	.475	.169	.061	.609	.164
Taylor's best iron	.198	.527	.155	.066	.657	.191
Bowling best iron	.225	.518	.150	.052	.598	.192
Farnley best iron	.173	.573	.167	.069	.708	.217
Lowmoor best iron	.212	.539	.166	.087	.597	.209
Best iron mean	.195	.526	.161	.067	.633	.194
Landore mild steeel	.208	.480	.206	.120	.666	.234
Brown & Co.'s mild steel	.215	.560	.254	.147	.755	.310
Bolton Co.'s mild steel	.198	.544	.214	.117	.785	.250
Steel Co. of Scotland's mild steel	.207	.509	.222	.132	.739	.253
Mild steel mean	.207	.523	.224	.129	.736	.262

NOTE.—A loss of 1 pound per square foot per annum is equal to an average loss of 1-40th inch of thickness per annum.

TABLE II.—COMPARATIVE LOSS OF IRON AND STEEL, TAKING LOSS OF LOWMOOR IRON AS STANDARD.

	Cold water.			Atmosphere, London.	Boilers.				Mean of columns 1, 2, 4, 5, 7 and 8.
	Sea. B.	Bilge. C.	Mean of B. C.	A.	Zinc in boiler. D.	Mean of F. E.	Collier boiler. F.	P. & O. boiler. E.	
Parkhead com'n iron	.90	.77	.83	.94	.67	.94	.95	93	.86
Skerne common iron.	.64	1.03	.83	.91	.72	.89	.81	.97	.85
Leeds forge best iron	.79	.88	.83	1.01	.70	.90	1.02	.78	.86
Taylor's best iron..	.93	.98	.95	.93	.76	1.00	1.10	.91	.90
Bowling best iron....	1.06	.96	1.01	.90	.60	.96	1.00	.92	.91
Farnley best iron....	.82	1.06	.94	1.00	.79	1.11	1.19	1.04	.98
Lowmoor best iron..	1.00	1.00	1.00	1.00	1.00	1.00	1 00	1.00	1.00
Landore mild steel...	.98	.89	.93	1.24	1.38	1.12	1.12	1.12	1.12
Brown's mild steel...	1.01	1.04	1.02	1.52	1 69	1.37	1.27	1.48	1 33
Bolton mild steel....	.93	1.01	.97	1.28	1.35	1.25	1.31	1.20	1.18
Steel Co. of Scotland mild steel.........	.97	.94	.95	1.33	1.52	1.22	1.24	1.21	1.20

Table III. shows the results of the analyses of the several bright disks contained in series F.

Table III.—Analyses and Densities of the Respective Materials of which the Disks were Made.

Description of metal.	Manganesc.	Carbon-color test.	Sulphur.	Phosphorus.	Silicon.	Copper.	Cobalt and nickel	Density.
Parkhead common iron	trace.	.09	.027	.316	.020	.060	.15	7 618
Skerne common iron..........	.01	.10	.027	.193	.100	.021	—	7.705
Taylor's best iron................	trace.	.12	.005	.136	.013	.00	.05	7.745
Leeds forge best iron............	.03	.14	.028	.085	.110	.031	—	7.764
Bowling best iron...............	trace.	.11	trace.	.101	.100	.016	—	7.791
Farnley best iron.	.01	.11	.012	.096	.090	.016	—	7.779
Lowmoor best iron.	.01	.10	.022	.142	.120	.022	—	7.689
Landore mild steel..............	.64	.18	.074	.077	.013	.015	—	7.861
Brown & Co.'s mild steel.......	.11	.12	.077	.056	trace.	trace.	—	7.854
Bolton & Co.'s mild steel........	.52	.19	.068	.041	.060	trace	—	7.849
Steel Co. of Scotland's mild steel.	.26	.10	.035	.057	.032	tracc.	—	7.872

Note.—The disks analyzed were the bright ones of series F, which, as already stated, was suspended in a boiler supplied with water from a point in the Tyne where it is probably acidulated by the refuse from one of the local copper-works.

A comparison of Tables II. and III., which could trace the relation of the different impurities contained in commercial iron and steel to their corrosion, would be of great interest, but the rate of corrosion has been so varied, even in the same series, and the amount of impurities are so slight, that I have not been able to determine the effect of the different elements.

A comparison of the densities and the corrosion shows the very reverse of what might have been expected from Mr. Mallet's experiments, for though they stand in no relation in series B and C, it appears as if in all others the denser metal has corroded fastest.

The hardening of the plates, by punching the numbers, in no way affected the corrosion of the bright disks, but the glass ferrules protected the part of the disk with which they were in contact when exposed to the atmosphere and bilge water. Curiously enough, however, in some of the cases in the boiler containing zinc, and in the sea, there was found to be considerable extra corrosion in the neighborhood of the glass.

BLACK DISKS.

With the black disks the glass had also protected parts of those disks subjected to the influence of bilge water and the atmosphere, while it had caused strong local corrosion on every one of the disks immersed in the sea and on about half of those exposed in the boiler containing zinc; and perhaps a still more curious circumstance is that throughout the experiments in the boilers the glass ferrules and glass tubes wasted more than the metals, being reduced to about half their original thickness.

The stamping of the numbers, which unavoidably caused some of the scale to come off, had an injurious effect on the plates exposed in the sea and the bilge, although the local corrosion from this cause was only slight in all the other cases.

To enable us to compare the corrosions of the black plates, it is necessary to divide the loss they sustained not by the total surface of the disks, but by the surface of the bare metal only. The percentage of exposed to total surface of each disk was therefore ascertained as nearly as possible, and will be found in Table IV.

A perusal of this table shows that, neglecting Lowmoor iron, which lost almost all its scale, the least scale has come off those disks immersed in the sea, namely, about 30 per cent.; next comes the series D, which was exposed in the boiler containing zinc, with 50 per cent.; followed by the two sets exposed to the atmosphere and in the bilges with an average of 70 per cent., while the plates in the boiler of the Peninsular and Oriental steamer lost 95 per cent. Those suspended in the boiler of the coasting ves-

TABLE IV.—RATIO OF UNPROTECTED METALLIC SURFACE OF BLACK DISKS TO TOTAL SURFACE AFTER EXPOSURE.

	Cold Water.		Atmosphere London.	Zinc in boiler.	Hot Water.		Mean of columns 1, 2, 3, 4.
	Sea. B.	Bilge C.	A.	D.	Collier boiler. F.	P. & O. boiler. E.	
Parkhead common iron	.70	.80	1.00	.60	1.00	1.00	.77
Skerne common iron	.30	.50	.90	.50	1.00	.90	.55
Leeds Forge best iron	.45	.85	.85	.80	1.00	1.00	.79
Taylor's best iron	.25	.50	.70	.30	1.00	.90	.44
Bowling best iron	.50	.90	1.00	.70	1.00	.95	.77
Farnley best iron	.30	.80	.95	.80	1.00	1.00	.71
Lowmoor best iron	1.00	1.00	1.00	.95	1.00	.98	.99
Landore mild steel	.30	.60	.50	.35	1.00	.90	.42
Brown's mild steel	.50	.80	.97	1.00	1.00	—	.82
Bolton mild steel	.15	.80	.50	.70	1.00	1.00	.54
Steel Co. of Scotland mild steel	.40	.80	1.00	.70	1.00	1.00	.72
Mean loss of scale due to stamping and exposure, exclusive of Lowmoor	.38	.73	.74	.54	1.00	.96	—

TABLE V.—RATIO OF AVERAGE DEPTH OF CORROSION OF BLACK DISKS TO BRIGHT DISKS.

	Cold Water.		Atmosphere, London.	Zinc in boiler.	Hot Water.	
	Sea. B.	Bilge. C.	A.	D.	Collier boiler. F.	P. & O. boiler. E.
Parkhead common iron	1.2	.9	1.1	1.8	.9	1.0
Skerne common iron	3.3	1.2	.8	2.1	1.0	.5
Leeds Forge best iron	2.4	1.0	.8	1.6	1.0	.8
Taylor's best iron	3.1	1.1	.8	3.1	1.1	.6
Bowling best iron	1.8	.8	1.0	2.5	1.1	.9
Farnley best iron	3.0	.5	.9	1.3	1.0	.9
Lowmoor best iron	.9	.9	1.1	1.3	1.1	.9
Landore mild steel	3.0	.9	.7	1.8	1.2	.9
Brown's mild steel	1.8	.9	1.0	.9	1.0	—
Bolton mild steel	.6	.6	.5	1.0	.9	.9
Steel Co. of Scotland mild steel	2.2	.8	1.1	1.1	1.0	1.1

sel lost all their scale, but this is easily accounted for by the fact that the glass ferrules broke during the last ten weeks of the exposure, thus allowing the disks to rub against each other.

Taking the mean values of the figures in columns 1, 2, 3, and 4, it will be seen that the Lowmoor iron has lost all scale; that Bowling iron, Leeds Forge iron, Parkhead iron, and Brown's steel have lost about 80 per cent.; Farnley Iron and Steel Company of Scotland steel about 70 per cent.; Skerne iron and Bolton steel about 55 per cent.; and Taylor's iron and Landore steel about 40 per cent. It should be mentioned, however, that in stamping the numbers before the experiments, it was observed that the Lowmoor scale appeared to be the softest, and fell off more easily than any other, while the other scales adhered better, but with different degrees of tenacity.

With the help of Table IV., and the accurately ascertained loss of each blank sample, and also the losses per annum per square foot of bright samples as given in Table I., we are able to compare the average depth of corrosion of the bright disks and that of the black disks where the scale has been removed. These results are given in Table V.

Looking at Tables IV. and V., it will be seen that the black disks which lost least scale, have corroded to a greater depth than the corresponding bright disks, and this can only apparently be accounted for by the galvanic action set up. The relative size of the exposed and protected (black scale) surfaces must have had some influence on the galvanic currents, but they appear to have been considerably affected by the different fluids to which the disks were exposed. If we thus assume that the black disks which corroded to a greater depth than the bright ones were acted upon galvanically, it would appear as if those in series D, which was exposed in the boiler containing zinc, had suffered more from galvanic action than the black disks in the other boilers, while the samples immersed in the sea suffered more than those exposed to the greasy water and moist air of the bilges, although the absolute loss of the respective bright disks was less. There is no practical difference between the loss of the black and the light disks exposed to the atmosphere, and it is evident that here at least no galvanic action could have taken place.

Without knowing how long the scale had been off, it is of course impossible to form a correct measure of the rate at which the black oxide might have been acting galvanically upon the neighboring bare patches, but the comparison is worth making, so far as it goes, and it certainly tends to confirm the belief mentioned by Mr. Barnaby and others, that a rather strong galvanic action does go on between the scale and the patches of bare metal in its neighborhood. Looking to the importance of this point, it is to be hoped that it will be further followed up and scientifically analyzed, as it seems to be from these experiments of quite as much importance as has been attributed to it.

As regards the protection afforded to the disks of series D, suspended in the boiler containing zinc, and, like the others, properly insulated from external galvanic action, the results would seem to indicated that this protection is due, not, as is generally supposed, to the galvanic action of the zinc, but either to the zinc salts, which gradually impregnate the boiling water, and possibly impart to it anti-corrosive properties, or to the action of the zinc, which, as it corrodes, absorbs all corrosive agents contained in the water. It would be interesting to ascertain by experiment what is actually the effect of dissolved zinc salts in boilers.

I have now endeavored to lay before the meeting the results of the series of experiments which it has been my privilege to make. I do not for a moment pretend to be able to account for all peculiarities that have arisen. Some degree of capriciousness was to be expected from those plates on which the scale was left, but I must confess I was hardly prepared to see so much difference between different steels and between different irons under precisely similar conditions as proved to be the case. It would perhaps not be far wrong, speaking generally, to say that the different pieces of iron differed as much among themselves as they did from steel; and certainly the effect produced on my mind, after carefully weighing the results of the experiments, has not been to raise any apprehension that steel boilers or steel ships are likely in the future to corrode to any serious extent more rapidly than iron.

Having made these experiments, however, I desire to say that I do not think undue importance should be attached to any experiments of the kind made on a small scale. The most they can do is to indicate tendencies, and perhaps suggest remedies and precautions earlier than actual experience, which necessarily takes some years to accumulate when a new material is placed under trying conditions. The only real test, however, and the only one that will be finally accepted, is that of practical experience with the boilers themselves.

We have at the present time some 1,100 marine steel boilers running, the majority of which come periodically under the inspection of the engineer-surveyors of Lloyd's Register, and although they have received instructions to give these boilers special attention and to note carefully any peculiarities they may discover, the accounts I have received from them down to the latest go to show that the steel boilers behave in respect to corrosion about as well as iron boilers. In one or two vessels also where an iron and a steel boiler are working under identical conditions, there is nothing to point to the conclusion that the iron will outlast the steel one. Greater irregularity in the corrosion of the steel is reported, and I am inclined to the belief that this is due, even to a greater extent than shown in the experiments, to the unequal action of the scale, and if it should be found necessary hereafter to remove the scale, the difficulties in the way would not be great, and much of the irregularity and pitting would doubtless be removed. This I know is being done to a limited extent in boilers. The Admiralty also have taken steps to remove the black scale from their ships, and I have heard of at least one firm intending to follow their example. At any rate, I feel sure this meeting will hear with satisfaction that neither from the series of experiments which I have described, nor from our daily experience up to the present time, is there any reason to believe that the question of corrosion is likely to form a bar to the extended use of steel for marine boiler-making purposes. Difficuties may arise, and some unexpected results may be found, but the difficulties will, in my opinion, be easily removed, and the members of this Institute will, I am sure, welcome any one who will lay before them unexpected results, and will assist him in obtaining an explanation of them.

RESULTS OF EXPERIMENTS ON MECHANICAL MOTORS FOR TRAMWAYS MADE BY THE JURY ON RAILWAY APPLIANCES AT THE ANTWERP EXHIBITION.

By Captain DOUGLAS GALTON, D.C.L., C.B., F.R.S.

From the "Journal of the Society of Arts."

An interesting feature of the International Exhibition at Antwerp was the competition which was invited between different forms of mechanical motors on tramways for use in towns, and between different forms of engines for use on light railways in country districts, or as these are termed, *Chemins de Fer Vicinaux.*

These latter have obtained a considerable development in Belgium, Italy, and other Continental States, and are found to be most valuable as a means of cheapening the cost of transit in thinly-peopled districts. But, owing to the fact that the Board of Trade regulations in this country have not recognized a different standard of construction for this class of railway from that adopted on main lines, there has been no opportunity for the construction of such lines in England.

There has, however, been a great development of tramway lines in England, which in populous districts supply a want which railways never could fully respond to; and although hitherto mechanical traction has not attained any very considerable extension, it is quite evident that if tramways are to fulfill their object satisfactorily, it must be by means of mechanical traction.

It is also certain that the mechanical motor which shall be found to be most universally adaptable, that is to say, most pliant in accommodating itself to the various lines and to the varying work of the traffic, will be the form of motor which will eventually carry the day.

The competition between different forms of motors at the Antwerp Exhibition, which was carefully superintended, and which was arranged to be carried on for a reasonable time, so as to enable the qualities and defects of the different motors to be ascertained, affords a starting point from which it will be possible to carry on future investigations.

I have, therefore, thought it advantageous to the interests of the community in this country to bring the results arrived at before this Society; and as the *Chemins de Fer Vicinaux*, to which one part of the competition was devoted, have no counterpart in this country, it is proposed to limit the present paper to an account of the experiments made on the motors for tramways.

Certain conditions were laid down in the programme published at the opening of the Exhibition, to regulate the competition, in order that the competitors might understand the points which would be taken into account by the judges in awarding the prizes.

The experiments were made upon a line of tramway laid down for the purpose in the City of Antwerp, carried along the boulevards from near the main entrance of the Exhibition to the vicinity of the principal railway station, a distance of 2,292 meters.

The line ended in a triangle of 505 meters, in order that those motors which required to run always in the same direction, should be enabled to do so.

Out of the whole length of the line, viz., 2,797 meters, 2,295 meters were in a straight line, 189 meters in curves of $1\frac{3}{4}$ chain radius, and 313 meters in curves of 1 chain radius. There were, on the line, four passing places, besides a passing place at the terminus; these were joined to the main line by curves of $1\frac{3}{4}$ chain radius.

The line was practically level, the steepest incline being 1 in 1,000; this circumstance is somewhat to be regretted, but the City of Antwerp afforded no convenient locality where a line with steep gradients could have been obtained. The motors were kept in sheds close to the commencement of the line of tramway near the Exhibition, where all necessary cleaning and such minor repairs as were required could take place.

A regular service was established, according to a fixed time-table, to which each motor was required to conform. Each journey was reckoned as starting from the end near the Exhibition, proceeding to the beginning of the triangle, and returning to the starting point. An hour was allowed between the commencement of each journey, fourteen minutes were allowed for a stoppage at the end near the Exhibition, and eighteen minutes at the other end—thus allowing 28 minutes for traveling 2 miles 1,500 yards, or a traveling speed of about 6 miles an hour. The motors were required to work four days out of six, and on one of the four days to draw a supplementary carriage.

An official, assisted by a storekeeper, was appointed to keep a detailed record—

1. Of the work done by each of the motors.

2. Of any delays occurring on the journey, and of the causes of delay.

3. Of the consumption of fuel, both for lighting the fires and for working.

4. Of the consumption of grease.

5. Of the consumption of water.

6. Of all repairs of whatever nature.

7. Of the frequency of cleaning and other necessary operations required for the efficient service of the motor.

The experiments lasted about four months. Five competitors offered themselves, which may be classed as follows: Three were propelled by the direct action of steam, and two were propelled by stored-up force supplied from fixed engines.

PROPELLED BY THE DIRECT ACTION OF THE STEAM.

1. The Krauss locomotive engine, separate from the carriage.

2. The Wilkinson locomotive engine (*i. e.*, Black and Hawthorn), also separate from the carriage.

3. The Rowan engine and carriage combined.

PROPELLED BY STORED-UP FORCE.

4. The Beaumont compressed-air engine.

5. The electric carriage.

It is somewhat to be regretted in the public interest, that other forms of mechanical motors, such as the Mekarski compressed-air engine, or the engine worked with superheated water, or cable tramways, or electrical tramways, were not also presented for competition.

1. The Krauss locomotive is of the general type of a tramway locomotive, but with certain specialties of construction. It has coupled wheels. The weight is suspended on three points. The water-tanks form part of the framing on each side; a covering conceals all except the dome of the boiler. Above the roof is a surface condenser, consisting of 108 copper tubes placed transversely, each of which has an external diameter

of 1.45 inches. The boiler is similar to that of an ordinary locomotive; its axis is 3 ft. 10½ in. above the road. The body of the engine is 9 ft. 11 in. long, and 7 ft. 2½ in. wide. The axles are 4 ft. 11 in. from center to center. The platform extends along each side of the boiler; the door of the fire-box is in the axis of the road. The engine-driver stands on the right-hand side, in the middle of the motor, where he has command of all the appliances for regulating the movements of the engine as well as of the brake.

The Wilkinson (Black and Hawthorn) engine had a vertical boiler and machinery. The cylinders were on the opposite side of the boiler from the door of the fire-box, and mounted independently; the motion of the piston was communicated by means of a crane shaft and toothed wheels to the driving axle. The wheels were coupled. A regulator-injector, and hand-brake were placed at each end, so that the engine driver could always stand in the front, whichever was the direction in which the engine moved; and there was a platform of communication between the two ends, carried along one side of the boiler.

The boiler was constructed with "Field" tubes, the horizontal tube plate having a flue in the middle which carried the heated gases into the chimney.

The visible escape of the steam is prevented by superheating. To effect this the steam, as it leaves the cylinder, passes into a cast-iron chamber adjacent to the boiler, which is intended to retain the water carried off with the steam. From thence the steam passes into a second chamber, suspended at a small height above the grate in the axis of the boiler and of the flue which conveys the heated gases into the chimney, and thence into a sort of pocket enclosed in the last-mentioned chamber, which is open at the bottom, and the upper part of which terminates in a tube passing into the open air. This method of dissipating the steam avoids the necessity of a condenser; but if it be admitted that the steam, in escaping, has a minimum temperature of 572° Fahr., it will carry away 12 per cent. more caloric than would have been required to raise it to a pressure of 150 lbs. per square inch.

The steam escaping through the safety valve is passed through the same apparatus.

The toothed wheel on the driving axle is arranged to act upon another toothed wheel on a shaft connected with the regulator, so as to control its speed automatically.

The length of the engine is 10 ft. 10 in., its width 5 ft. 9 in., and the distance from center to center of the wheels 5 ft. 2 in.

The Rowan tramcar consists of a body 31 ft. long and 7 ft. wide, resting on a two-wheeled bogie behind, and on a four-wheeled bogie in front, this front bogie being the motor, and the whole has the appearance of a long railway carriage, somewhat in the form of an omnibus with a platform at each end, of which the front platform is occupied by the engine. It requires, therefore, either a turntable or a triangle at the end of the line, so as to enable it to reverse its direction.

This motor is a steam-engine of light and simple form, supplied with steam from a water-tube boiler with very perfect combustion, so that no smoke escapes. The boiler is somewhat on the principle of a Shand and Mason boiler; it is so built that it can easily be opened and every part of the interior examined and cleaned.

The peculiarity of the Rowan motor is the simplicity of the attachment of the engine to the carriage, and the facility with which it can be detached when required for cleaning or repair, viz., in five or six minutes.

The steam can be got up in the engine with great rapidity if a change of engine is required. When, however, the engine is detached, the carriage loses its support in front and is therefore not serviceable. When necessary, the combined motor can draw a second ordinary carriage.

The motor, by itself, occupies a length of 9 ft. 8 in. It has two horizontal cylinders; the four wheels of the bogie are coupled, and between the wheels the sides of the framing are rounded to allow two vertical uoilers to stand. These boilers have vertical tubes for the water, which are joined together at the top by a horizontal cylinder. Each boiler, with its covering, is 1 ft. 9 in. in diameter. The boilers stand 1 ft. 9 in. apart, thus affording space between them for the motive machinery, including the pump. The crank axle is behind the boilers. The levers, the injector, the access to the fire-box, a pedal for working the engine-brake, as well as a screw brake for the carriage, are all in front. The brakes act on all six wheels, are worked by the driver, and the whole weight of the engine, car, and passengers being carried on these wheels, the car can be stopped almost instantaneously; and as over two-thirds of the entire weight of the car and passengers rests on the four driving wheels, there is always sufficient adhesion on all reasonable inclines, and the adhesion is augmented as the number of passengers carried increases. Hence, this car is adapted for lines with heavy grades.

A small water-tank is attached to the framing; two small boxes for coal or coke, with a cublic capacity of about $3\frac{1}{2}$ ft., are attached to the plate in front of the bogie. The covering of the boilers is in two parts, which are put on from each side horizontally, and screwed together in the center. The removal of the upper part enables the tubes to be examined and cleaned. The draught is natural; the base of the chimney is 3 ft. 2 in. from the grate; the height of the chimney is 5 ft. 2 in.

The steam from the cylinders passes directly into a condenser placed on the top of the carriage. The condenser is made of corrugated copper sheets a millimeter thick. Two sheets, about 15 to 18 in. wide and 15 ft. long, are laid together and firmly soldered, forming a chamber. Twenty of these chambers are placed side by side on the top of the carriage, connected with a tube at each end, so as to allow the steam to pass freely through them. The lower corrugations in the several chambers are connected together, and thence a pipe with a siphon to stop the steam is carried to a water tank under the carriage, which thus receives the condensed water. This arrangement afforded a condensing surface of about 800 sq. ft. It should be mentioned that, with larger engines, Mr. Rowan employs as much as 1,600 ft. of condensing surface. The nearness of the chambers to each other tends, no doubt, to diminish the power of condensing the steam, but this is somewhat compensated by the artificial circulation of air produced by the movement of the carriage. But, in any case, if there is surplus steam, the pipe from the condenser causes it to pass under the grate, whence it rises superheated and invisible through the fire and up the chimney.

Under the carriage, attached to the framing, are four reservoirs, holding about $3\frac{1}{2}$ cubic feet of water, of which water space one-half acts as a reservoir for cold feed-water, and half for the condensed water. A tube from the small reservoir on the engine communicates through valves with the reservoirs of hot and cold water on the carriage.

The consumption of cold water measured during two days was 2.86 lbs. per kilometer; assuming that the boiler evaporated 6.5 lbs. of water per pound of coal, the cold water formed one-fifth of the total feed-water required.

The carriage, *i. e.*, the part occupied by passengers, is 21 ft. 3 in. in length. It holds seats for forty-five passengers, besides those who would stand on the gangway and platform. The seats are placed transversely on each side of a central corridor, each seat holding two people. The platform of the carriage is about 2 ft. 6 in. above the rails. Passengers have access to the interior from behind by means of the end platform, and in front, near the engine, from the two sides. As already mentioned, the hind part of the carriage rests upon two wheels, the front part being, as already mentioned, supported on the engine bogie. To effect this support, the hinder part of the framing of the engine is formed in a half circle, with a broad groove, in which the ends of two springs are arranged to slide. The centers of the springs form the support of the framing of the carriage.

The framing of the engine bogie is attached to the hind bogie truck of the carriage by two diagonal drawbars. The coupling is effected by bolts close to the engine, and the car is drawn entirely by means of the bogie pin of the hind bogie. The trucks are 16.5 ft. apart.

Table I. (p. 205) shows the dimensions of different parts of these three steam motors, as well as their weights.

The Beaumont engine, worked by compressed air, may be generally said to be similar to that described in a paper read before the Society of Arts on the 16th

TABLE I.

		Krauss.	Wilkinson.	Rowan.
Diameter of cylinder....................	d	5.5 in.	6.5 in.	5.1 in.
Length of stroke........................	l	11.8 in.	9 in.	9.8 in
Diameter of wheels....	D	31.5 in.	27.5 in.	29.5 in.
Pressure at which boiler is worked.......	p	220 lbs.	147 lbs.	191 lbs.
$\frac{p\,d^2 l}{2.D}$..................................	E	1,210 lbs.	1,509 lbs.	805 lbs.
Total heating surface.....	S	105 sq. ft.	105 sq. ft.	64 sq. ft.
Grate surface............................	G	2.7 sq. ft.	5.4 sq. ft.	3.1 sq. ft.
Surface of condenser.................	C	274.482 sq .ft.	None.	861.120 sq. ft.
Weight in running order (motor only)....	P′	15,400 lbs.	15,400 lbs.	9,020 lbs.
" " " (total)........	P″	..	..	15,400 lbs.
Contents of water tank..................	..	28.24 cu. ft.	13 cu. ft.	4.2 cu. ft.
" coal bunks..................	..	14.12 cu. ft.	12.5 cu. ft.	3.5 cu. ft.
	$\frac{P'}{E}$	12.7 lbs.	10.2 lbs.	11.2 lbs.
	$\frac{P''}{E}$	..	..	19.125 lbs.
	$\frac{P'}{S}$	146	147	140
	$\frac{P'}{G}$	5,722	2,855	2,889
	$\frac{C}{S}$	2.6	..	13.4
	$\frac{C}{G}$	102	..	275

of March, 1881, to which, however, some improvements have been since introduced.

The apparatus for compressing the air was placed in the shed. The air was compressed to 63 atmospheres by a pump worked by a steam-engine, and stored in cylindrical reservoirs of wrought iron without rivets. A pipe led the air from the reservoirs to the head of the tramway, where the cylinder placed on the motor for storing the air during the journey could be conveniently charged.

The air was compressed by means of four pumps, placed two and two in a water-box, and worked by the direct action of a compound engine with cylinders placed in juxtaposition, of 8 in. and 14 in. diameter respectively, with an equal length of stroke of 13 in.

The air, after being forced through the first pump cylinder, passed successively through the other three, the diameters of which were of proportionately decreasing sizes, viz.: 8.2 in., 5 in., 3.5 in., and 2 in., and the air, on leaving each cylinder, passed on its way to the next cylinder through a coiled pipe immersed in flowing water to remove the heat generated. This cooling surface amounted to nearly 54 sq. ft.

The cooling of the air was very efficient. In an experiment made on this question, the temperature of the compressor did not vary to the extent of 9° Fahr. in charging the reservoir from 40 to 63 atmospheres, occupying an hour and a-half, the consumption of water during the time being about 1,400 gallons.

The fixed reservoirs were of about 240 cu. ft. capacity.

The motor formed part of a compound vehicle, which may be said to have consisted of two parts joined together by an articulated corridor, the whole being covered by a roof which was approached from the platform behind by an easy staircase. On this roof were seats for outside passengers.

The front part of the compound vehicle contained the motor, as well as a compartment for six inside passengers, with roof space for twenty passengers, and weighed about 15,400 pounds when empty; the hind part contained accommodation inside for twelve passengers, and outside for fourteen passengers, and weighed 6,600 lbs.

The combined vehicle was entered from the platform in the rear, which could hold four passengers, and from thence, as already mentioned, the staircase led on to the roof. The total number of passengers this vehicle could accommodate was thus—eighteen inside, thirty-four on the roof, four on the platform, or, fifty-six in all.

The total length of the carriage was 29 ft. 7 in., width 7 ft. The distance between the axes of the bogies was 16 ft. 9 in. The distances apart of the centers of the wheels were, in the case of the hind bogie, 3 ft. 9 in., and in the case of the front bogie, 4 ft. 4.6 in.

The motor is a compound engine, the diameters of the cylinders being 4.9 in., and 1.9 in., with 12 in. stroke. The diameter of the wheels was 2 ft. 4 in. A small boiler is placed on one side, in front, for creating steam, which passes into a steam-jacket, enclosing the pipe of communication from the reservoir to the cylinders, as well as the cylinders themselves, so that the air was warmed before it escaped. The reservoirs on the motor contained 71 cu. ft.

In an experiment made on charging the reservoir in the motor, the pressure in the fixed reservoirs, at the time of charging the reservoirs on the motor, was 63.8 atmospheres, at a temperature of 68° Fahr. One atmosphere was lost by letting the air into the pipe laid between the shed and the tramway where the motor stood; when the reservoir on the motor was charged, the pressure fell to 42.6 atmospheres in the fixed reservoirs, at a temperature of 55° Fahr.

The pressure in the reservoir on the motor, when ready to start, was 42.6 atmospheres, at a temperature of 84° Fahr. On its return at the end of forty-six minutes, after a journey, as above mentioned, of about 3¼ miles, including the triangle, the pressure had fallen to 20.9 atmospheres, and the temperature to 71° Fahr. The weight of air used during the journey was thus about 110 lbs., or, say, 34 lbs. per mile. The coal consumed by the stationary engine to compress the air amounted to 39 lbs. per mile, in addition to 3 lbs. of coke per mile for warming the exhaust.

Whilst the motor was performing its journey, the stationary steam-engine was employed in raising the pressure in the fixed cylinders to 63 atmospheres, and worked, on an average, during fifty minutes in each hour; during the rest of the journey it remained idle. It was thus always employed in doing work in excess of the pressure which could be utilized on the car, and the work was, under the circumstances of the case, necessarily intermittent. This was a very unfavorable condition of working.

In the electric tram-car the haulage was effected by means of accumulators. The car was of the ordinary type, with two platforms. It was said to have been running as an ordinary tramcar since 1876. It had been altered in 1884 by raising the body about six inches, so as to lift it clear of the wheels, in order to allow the space under the seats to be available for receiving the accumulators, which consisted of Faure batteries of a modified construction. The accumulators employed were of an improved kind, devised by M. Julien, the under manager of the Compagnie l'Electrique, which undertook the work.

The principal modification consists in the substitution, for the lead core of the plates, of one composed of a new unalterable metal. By this change the resistance is considerably diminished, the electromotive force rises to 2.40 volts, the return is greater, the output more constant, and the weight is considerably reduced. The plates being no longer subject to deformation, have the prospect of lasting indefinitely. The accumulators used were constructed in August, 1884.

The car, as altered, had been running as an electric tramcar on the Brussels tramways since October, 1884, till it was transferred to the experimental tramway at Antwerp. The accumulators had been in use upon the car during the whole of this period, and they were in good order at the end of the experiments, that is to say, when the Exhibition closed at the end of October, 1885.

The accumulator had forty elements, divided into four series, each series communicating by means of wires fixed to the floor of the car, with commutators which connected them with the dynamo used as a motor.

There were two sets of these batteries, or accumulators, one of which was being charged in the shed whilst the other was in use. The exchange required ten minutes, including the time for the car to go off the tramway into the shed and return to the tramway. This exchange took place after every seven journeys. Therefore, the two batteries would have sufficed for working the car over a distance of about 42 miles during 16 hours.

It may be observed that the first service in the morning would be performed by means of the accumulators charged during the afternoon and evening of the previous day.

Each element of a battery was composed of 19 plates, of which 9 were positive, 4 millimeters thick, and 10 negative, 3 millimeters thick. Each positive plate weighed 1.44 lbs., of which about 25 per cent. consisted of active material. Each negative plate weighed nearly 1 lb., of which one-third consisted of active matter. The weight of the metallic part of the battery amounted, therefore, to 1,846 lbs.; and the whole battery, including the case and the liquid, amounted to 2,464 lbs., which contained 499 lbs. of active matter, or 20.25 per cent. The four cases in which the battery was contained were so arranged as to divide the weight equally between the wheels.

Two commutators enclosed in a box were placed on the platforms at the two ends of the carriage, so as to be available for moving in either direction.

The accumulators were divided into four series of ten double elements, which, by means of the commutators, could be united under four combinations, viz.:

1st. 4 series in quantity—1 in tension.
2d. 2 " " " 2 "
3d. ....3 "
4th. ....4 "

Finally, a fifth movement united the four series in quantity, coupling them on each other, and putting the dynamo out of circuit, thus restoring equilibrium. When in a state of repose the handle was so arranged as to keep this latter switch turned on. The accumulators were arranged for charging in two series united in quantity, each containing twenty double elements. The charge was effected by a Gramme machine, worked by a portable engine. Each of these series received its charge during seven hours for the ordinary service of the car, and during nine hours for the accelerated service.

The accumulators on the car actuated a Siemens dynamo, acting as a motor, such as is used for lighting, having a normal speed of 1,000 revolutions, fixed on the frame of the carriage. The motion was conveyed from the pulley on the dynamo by means of a belt passing round a shaft fixed on movable bearings to regulate its tension, and thence to the axles by means of a flat chain of phosphor-bronze. The chain was adopted as the means of moving the axle, on account of its simplicity and facility of repair by unskilled labor.

The speed was fixed at 4 meters per second (which corresponds with a speed of nearly 9 miles per hour), for 1,000 revolutions of the dynamo, and it was regulated by cutting a certain number of the accumulators out of circuit, instead of by the device of inserting resistances which cause a waste of energy. By breaking the circuit entirely the motive power ceased, and the vehicle might either be stopped by the brakes or allowed to run forward by gravity, if the road were sufficiently inclined. The reversal of the motor was effected by means of a lever which reversed the position of the brushes of the dynamo.

The dynamo could be set in motion, and the carriage worked from either end, as desired. The handle to effect this was movable, and as there was only one handle and this one was in charge of the conductor, he used it at either end as required.

It should be mentioned that the car was lighted at night by two incandescent lamps, which absorbed 1.5 amperes each; and the brakes also were worked by the accumulators.

The weight of the tramcar was 5,654 lbs.; the weight of the accumulators was 2,460 lbs.; the weight of the machinery, including dynamo, 1,232 lbs. The car contained room for fourteen persons inside and twenty outside. Under the conditions of the competition the car was required to draw a second car occasionally.

The jury made special observations upon the work required to move the car between the 20th September and 15th October, 1885. Seals were attached to the accumulators. Moreover, from the

27th of September, after each charge, seals were placed on the belts from the steam-engine to prevent any movement of the Gramme machine, so that there could be no charges put into the accumulators beyond those measured by the jury.

The instruments used for measuring were Ayrton's ampere meter and Deprez's volt meter, which had been tested in the Exhibition by the Commission for Experiments on Electrical Instruments, under the presidency of Professor Rousseau. Besides this, Siemens electro-dynamometer and Ayrton's voltmeter were used to check the results; but there was no practical difference discovered. During the period of charging the accumulators, the intensity of the current and the electromotive force was measured every quarter of an hour, and thence the energy stored up in the battery was deduced. It may be mentioned that the charge in the accumulators, when the experiments were commenced, was equal in amount to that at their termination.

An experiment was made on 21st October to ascertain, as a practical question, what was the work absorbed by the Gramme machine in charging the accumulators. The work transmitted from the steam-engine was measured every quarter of an hour by a Siemens dynamometer, at the same time the intensity of the electromotive force given out by the machine, as well as the number of the revolutions it was making, was noted. It resulted that for a mean development of 4 mechanical horse-power, the dynamometer gave into the accumulators to be stored up 2.28 electrical horse-power, or 57 per cent. The intensity varied between 25.03 and 23.51 amperes during the whole time of charging. Of this amount stored up in the accumulators a further loss took place in working the motor; so that from 30 to 40 per cent. of the work originally given out by the steam-engine must be taken as the utmost useful effect on the rail.

It was estimated that to draw the carriage on the level .714 horse-power was required, or, if a second carriage was attached, .848 horse-power would draw the two together. This would mean that, say, 2 horse-power on the fixed engine would be employed to create the electricity, for producing the energy required to draw the carriage on the level.

The electric tramcar was quite equal in speed to those driven by steam or compressed air, and was characterized by its noiselessness and by the care with which it was manipulated.

Assuming the car, by itself, cost the same as an ordinary tramcar, the extra cost relatively to other systems was stated as being, according to the following figures, viz.: The Gramme machine cost £48, the motor £208, and the accumulators 2.25 francs per kilogramme (10d. per pound). To these must be added the cost of erection, and of switches for manipulating the current; as well as the proportion of the cost of a fixed engine to create the electricity.

Having thus given a general description of the various motors which were presented for competition, I will now give a brief summary of some of the principal particulars obtained during the competition. In the first place, it may be mentioned that the Jury consisted of the following:

President.—M. Hubert, Ingénieur en Chef, Inspecteur de Direction à l'administration des chemins de fer de l'Etat Belge.

Vice-President.—M. Beliard, Ingénieur des Arts et Manufactures, délégué par le Gouvernement Francais.

Members.—MM. Douglas Dalton, Capitaine du Génie, délégué par le Gouvernement Anglais; Gunther, Ingénieur Commissaire Général de la Section Allemande à l' Exposition d'Anvers; Hubert, Ingénieur à l'administration des chemins de fer de l'Etat Belge, Professeur à la Université de Bruxelles; Dery, Ingénieur Chef de service a l'administration des chemins de fer de l'Etat Belge.

Secretary.—M. Dupuich. Ingénieur Chef du service du matérial et de la traction à la Société Générale des chemins de fer économiques.

Reporter.—M. Belleroche, Ingénieur en Chef, a la traction et au matérial des chemins de fer du Grand Central.

Members added by the Jury.—MM. Vinçotte, Ingénieur, Directeur de l' Association pour la surveillance des machines a vapeur; Laurent, Ingénieur des mines et de l'Institut électro-technique de l'Universite de Liége.

The original programme of the conditions which were laid down in the invitation to competitors, as those upon which the adjudication of merit would be awarded, contained twenty heads, to each of which a certain value was to be attached ; and, in addition to these special heads, there were also to be weighed the following general considerations, viz:

a. The defects or inconveniences established in the course of the trials.

b. The necessity or otherwise of turning the motor, or the carriage with motor, at the termini.

c. Whether one or two men would be required for the management of the engine.

As regards these preliminary special points, the compressed-air motor, as well as the Rowan engine, required to be turned for the return journey, whereas the other motors could run in either direction.

In regard to this, the electric car was peculiarly manageable, as it moved in either direction, and the handle by which it was managed was always in front, close to the brake. This carriage was the only one which was entirely free from the necessity of attending to the fire during the progress of the journey, for even the compressed-air engine had its small furnace and boiler for heating the air.

Each of the motors under trial was managed by one man.

The several conditions of the programme may be conveniently classified in three groups, under the letters A, B, C. Under the letter A have been classed accessory considerations, such as those of safety and of police. These are of special importance in towns. But their relative importance varies somewhat with the habits of the people as well as with the requirements of the authorities ; for instance, in one locality or country conditions are not objected to, which in another locality are considered entirely prohibitory.

The conditions under this head are:

1. Absence of steam.

2. Absence of smoke and cinders.

3. Absence, more or less complete, of noise.

4. Elegance of aspect.

5. The facility with which the motor can be separated from the carriage itself.

6. Capacity of the brake for acting upon the greatest possible number of wheels of the vehicle or vehicles.

7. The degree to which the outside covering of the motor conceals the machinery from the public, whilst allowing it to be visible and accessible in all parts to the engineer.

8. The facility of communication between the engineer and the conductor of the train.

In deciding upon the relative merits of the several motors, so far as the eight points included under this heading are concerned, it is clear that, except possibly as regards absence of noise, the electrical car surpassed all the others.

The compressed-air car followed, in its superiority in respect of the first three points, viz., absence of steam, absence of smoke, and absence of noise; but the Rowan was considered superior in respect of the other points included in this class.

Under the letter B have been classed considerations of maintenance and construction.

9. Protection, more or less complete, of the machinery against the action of dust and mud.

10. Regularity and smoothness of motion.

11. Capacity for passing over curves of small radius.

12. The simplest and most rational construction.

13. Facility for inspecting and cleaning the interior of the boilers.

14. Dead weight of the train compared with the number of places.

15. Effective power of traction when the carriages are completely full.

16. Rapidity with which the motor can be taken out of the shed and made ready for running.

17. The longest daily service without stops other than those compatible with the requirements of the service.

18. Cost of maintenance per kilometer, (It was assumed, for the purposes of this sub-heading, that the motor or carriage which gave the best results under the conditions relating to paragraphs 9, 10, 12, and 13, would be least costly for repairs.)

As regards the first of these, viz., protection of the machinery against dirt, the machinery of the electrical car had no protection. It was not found in the experiments at Antwerp that inconvenience resulted from this; but it is a question whether in very dusty localities, and especially in a locality where there is metallic dust, the absence of protection might not entail serious difficulties, and even cause the destruction of parts of the machinery.

In respect of the smoothness of motion and facility of passing curves, the cars did not present very material differences, except that the cars in which the motor formed part of the car had the preference.

In the case of simplicity of construction, it is evident that the simplest and most rational construction is that of a car which depends on itself for its movement, which can move in either direction with equal facility, which can be applied to any existing tramway without expense for altering the road, and the use of which will not throw out of employment vehicles already used on the lines; the electric car fulfilled this condition best, as also the condition numbered 13, as it possessed no boiler.

In respect to No. 14, viz., the ratio of the dead weight of the train to passengers, if we assume 154 lbs. as the average weight per passenger, the following is the result in respect of the three cars in which the power formed part of the car:

$$\text{Electric car} \ldots\ldots \frac{9{,}350 \text{ lbs.}}{154\times 34} = 1.78.$$

$$\text{Rowan} \ldots\ldots\ldots\ldots \frac{15{,}950 \text{ lbs.}}{154\times 45} = 2\ 30.$$

$$\text{Compressed air} \ldots \frac{22{,}000 \text{ lbs.}}{154\times 56} = 2.55.$$

The detached engines gave, of course, less favorable results under this head.

Under head No. 15 the tractive power of all the motors was sufficient during the trials, but the line was practically level, therefore, this question could only be resolved theoretically, so far as these trials were concerned, and the table before given affords all the necessary data for the theoretical calculation.

As regards the rapidity with which the motors could be brought into use from standing empty in the shed, the electric car could receive its accumulators more rapidly than could the boiler for heating the exhaust of the compressed-air car be brought into use.

As regards the steam motors, the following were the results from the time of lighting the fires:

The Rowan—

In 34 minutes............3 atmospheres.
36 " ....4 "
(At this pressure the vehicle could move.)
40 " ....8 "

The Wilkinson—

In 35 minutes............2 atmospheres.
40 " ....4 "
44 " ....6 "
47 " ....8 "

The Krauss machine required two hours to give 6 atmospheres, which was the lowest pressure at which it could be worked.

The results under No. 17, viz., the fewest interruptions to the daily service, class the motors in the following order—Krauss, electric, Rowan, Wilkinson, compressed air. The chief cause of injury to the compressed-air motor arose from the carelessness of the drivers, who allowed the steam boiler to be burnt out. Unfortunately, these drivers were new to the work.

Under the letter C are classed considerations of economy in the consumption of materials used for generating the power necessary for working.

19. Minimum consumption of fuel (either coke or coal), in proportion to the number of kilometers run, and to the number of places, assuming for the seats a width of at least sixteen inches for each person seated.

It must be borne in mind that the conditions of the competition required that a second car should be periodically drawn by the motor, and that the calculations which follow include the total number of

TABLE II.

Description of motor.	Total number of train-miles run.	Total consumption of fuel.	No. of lbs. per train-mile.
		lbs.	
Electric.......	2,358.9	14,786.	6.16
Rowan.......	2,616.9	14,498.	5.42
Wilkinson....	2,473.3	22,000.	8.82
Krauss.......	2,457.8	22,726.	9.10
Compressed air	2,259.1	90,420.	39.48

miles run, the total amount of fuel, etc., consumed; and the total number of passengers which could be conveyed by each moter, during the total time that the experiments were being carried on.

TABLE III.

Description of motor.	No. of places indicated on the cars, per mile run.	Consumption of fuel.	No. of lbs. of fuel consumed per places indicated per mile run.
		lbs.	
Electric.......	80,203.5	14,786.	.18
Rowan.......	148,399.6	14,498.	.09
Wilkinson....	119,085.1	22,000.	.18
Krauss.......	108,983.9	22,726.	.20
Compressed air	128,189.3	90,420.	.69

TABLE IV.

Description of motor.	No. of seats per mile run.	Consumption of fuel.	No. of lbs. of fuel consumed per seat per mile run.
		lbs	
Electric.......	61,591.2	14,786.	.23
Rowan........	135,928.8	14,498.	.10
Wilkinson....	93,965.6	22,000.	.23
Krauss.......	86,039.9	22,726.	.25
Compressed air	132,732.7	90,420.	.66

As regards the figures in these tables, it is to be observed that the consumption of fuel for the electric car is, to a certain extent, an estimate; because the engine which furnished the electricity to the motor also supplied electricity for electric lights, as well as for an experimental electric motor which was running on the lines of tramway, but was not brought into competition.

20. Minimum consumption of oil, of grease, tallow, etc. (the same conditions as in No. 19.)

TABLE V.

Description of motor.	Total number of miles run.	Total consumption of oil, tallow, etc.	Consumption of oil, tallow, etc., per train-mile run.
		lbs	
Electric......	2,358.9	99.0	.038
Rowan	2,616.9	106.7	.038
Krauss.......	2,457.8	188.5	.073
Wilkinson....	2,473.3	255 4	.101
Compressed air	2,259.1	585.2	.255

In addition to these considerations, it was thought useful to investigate the quantity of water consumed in the case of these engines which used steam. The experiments made on this point showed as the consumption of water—

	Gallons per mile.
Rowan........................	.75
Compressed air................	1.06
Wilkinson.................	5.89
Krauss	6.52

Thus, owing to the large proportion of water returned from the condenser to the tanks, the Rowan actually used less water than the compressed-air engine.

CONCLUSION.

The general conclusion to which these experiments bring us is that, undoubtedly, if it could certainly be relied upon, the electric car would be the preferable form of tramway motor in towns, because it is simply a self-contained ordinary tramcar, and in a town the service requires a number of separate cars, occupying as small a space each as is compatible with accommodating the passengers, and which follow each other at rapid intervals.

But the practicability and the economy of a system of electric tramcars has yet to be proved; for the experiments at Antwerp, whilst they show the perfection of the electric car as a means of conveyance, have not yet finally determined all the questions which arise in the consideration of the subject. For instance, with regard to economy, the engine employed to generate the electricity was not in thoroughly good order, and from its being used to do other work than charg ing the accumulators of the tramcar, the consumption of fuel had to be to some extent estimated. In the next place, the durability of the accumulators is still to be ascertained; upon this much of the economy would depend. And in addition to this question, there is also that of the durability of parts of the machinery if exposed to dust and mud.

After the electric car, there is no question but that, at the Antwerp Exhibition, the most taking of the tramway motors was the Rowan, which was very economical in fuel, quite free from the appearance of steam, and very convenient and manageable.

The economy of the Rowan motor arises in a large degree from the extent of its condensing power, by means of which a considerable supply of warm water is constantly supplied for use in the boiler, and, consequently, the quantity of water which has to be carried is lessened, and the fuel is economized.

Independently, however, of its convenience as a motor for tramways in towns, the Rowan machine has been adapted on the Continent to the conveyance of goods as well as passenger traffic on light branch railways, and fitted to pass over curves of 50 ft. radius, and up gradients of 1 : 10.

In England, with our depressed trade and agriculture, there is a great want in many parts of the country of a cheap means of conveyance from the railway stations into the surrounding districts; such a means of conveyance might be afforded by light railways along or near the roadside, the cost of which would be comparatively small, provided that the expensive methods of construction, of signaling, and of working, which have been required for main lines, and which are perfectly unnecessary for such light railways, were dispensed with.

It is certain that this question will acquire prominence as soon as a system of local government has been adopted, in which the wants of the several communities have full opportunity of asserting themselves, and in which each local authority shall have power to decide on those measures which are essential to the development of the resources of its own district, without interference from a centralized bureaucracy.

Discussion.

Mr. Preece, F. R. S., said he was a juryman at the Antwerp Exhibition, and though his official duties did not require him to inspect and report upon these tramcars, he took every possible opportunity of examining them, and being an electrician, of traveling backwards and forwards on the electric car. He was delighted to find that the anticipations he formed, at an early period of the Exhibition, had been fully borne out by what Captain Galton had said. At the same time it was rather difficult to discover in what respect this particular car differed from others of a similar kind which had been experimented on in England. The chief advantage it had, seemed to him to be that it had been examined and reported on by Captain Douglas Galton. One very similar ran backwards and forwards for some time in the works of the Electric Power Storage Company at Millwall, and one designed by Mr. Reckenzaun had been running some time in Berlin. He tried to find out the special features of the accumulator used by M. Julien, but failed to do so. It was said to be formed on a framework of some unalterable metal, but he did not discover what it was; he heard by a side-wind that it was nickel, but at any rate, as far as the performance and appearance went, he could see no difference between it and those used in England. At different times, he had inspected and ridden on various electric tramcars, some driven direct by the current, like that at Portrush, or the one at Cleveland, United States, the only difference in these two being that the current in Ireland was of low tension, and that in the United States was of high tension. There was also one, which he had not seen, at Blackpool. As an electrician, he had seen very great difficulties in carrying out a system of tramways worked by electricity, but, like all other difficulties, experience and study succeeded in removing them, and he had the greatest confidence in the future use of electricity for this purpose, whether applied directly or by the aid of accumulators. There was a great want of confidence in this latter system, the reason for which was not hard to discover, because they were thrust on the world long before either it was ready to receive them or they were properly developed. One of the first places in which the tide began to turn was in the Society of Arts. Some time back they had succeeded in lighting the hall by means of accumulators, and all present could see with what absolute steadiness the light was maintained. Captain Galton, at the end of the paper, said that undoubtedly, if it could be relied on, electricity would be the best motor for tramways; and that was the way in which everyone spoke of it. But there was no power on earth used for the service of man which could be so certainly relied on as electricity. These doubts were due to the fact that the early applications of electricity were so striking in their character, such, for instance, as reproducing speech by the telephone, that they at once caught the attention of the public, who at once believed the thing was perfection before it had really reached the practical stage. So it was with the accumulator; the idea of storing up a horse-power in a deal box appealed to the public imagination, and when the fact was first published in the *Times*, that a certain gentleman brought such a box from Paris to Sir William Thomson, in Edinburgh, inordinate expectations were raised; then, when it was not found at first a practical instrument, they began to use such expressions as he had referred to, and thought it could not be relied on. He had no doubt, however, we should yet live to see in London and the suburbs, the Antwerp experiments repeated on a much larger scale.

Mr. A. Reckenzaun said this was one of the most interesting and practical papers ever read on the subject of the mechanical propulsion of tramcars, but it would have been still more useful had the experiments been carried out on a line presenting more difficulties. It was very easy to travel on a level line, but very difficult to travel on an incline. For instance, if it required 2 horse-power on the level, it would take 4 horse-power to go at the same speed up a gradient of 1 in 75, 6 horse-power for a gradient of 1 in 37, and 8 horse-power for 1 in 25, which was not very serious after all. Again, the sharpest curve on the line at Antwerp was only of a radius of one chain, and he was rather surprised it was not made sharper. He had recently been running a car in Berlin, where he had received much more encouragement than in London, and he believed a fair amount of business would be done there before any start was made in England at all. There, one curve was 11 meters radius, and there were several of 15 meters. In the Antwerp tram it appeared there was a certain amount of noise caused by the chain gear, and this kind of gearing was not very practical in the case of a tramway where there was a deal of dirt to guard against. He had adopted a worm wheel, such as was shown on a large drawing of his tramcar on the wall. Many experienced engineers advised him not to use this gearing, but having arranged it so that the wheel dipped into an oil bath, and the whole boxed in, so that little or no dirt could find access, he found that there was not nearly so much loss by friction as had been stated, previous experiments having all been made apparently at low speeds, and showing an efficiency varying between 30 and 50 per cent. He found, however, that he got as much as 80 to 85 per cent., which was as much as could be got with a chain. He had two motors, so that the speed or power could be varied at will. One motor would propel the car along a level road, and it would run down an incline of 1 in 70 by its own momentum, which showed how little friction there was. The two motors in parallel arc would drive it up an incline of 1 in 18, and the two were used in series at starting, when the electric resistance was greatest, so that the current flowing then should be the smallest possible. With regard to the wonderfully lasting accumulators which it was said M. Julien had discovered, he would only say that if the plates lasted only six or eight months electrical cars would still be more economical than horses. Although the efficiency of the whole apparatus between the steam-engine and the car-wheels could not be taken at more than 30 to 40 per cent. (he reckoned it at 33), still it was economical to use electricity, because the accumulators only weighed $1\frac{1}{4}$ ton, and the whole of the rest of the machinery weighed half a ton, making $1\frac{3}{4}$ ton altogether, which compared very favorably with a locomotive weighing eight to ten tons. You could therefore afford to lose 60 to 70 per cent. of your motive power. He ought to say that he was much indebted to the Electric Power Storage Company who had assisted him very materially in bringing this car to perfection. He had been working at it for four years, but it was only within the last twelve months he had arrived at a practical result. The first question was, to produce an accumulator which was light, and at the same time durable and efficient. The main advantages of this system were, first, economy, and, second, the electric car had the same appearance as those in general use, which could be easily converted, and at a small cost. The wearing parts of the mechanism were very few, and could be easily replaced. The weight of motive power was less than two tons, distributed over two small bogies of four wheels each, so that the actual weight on a given section of the rail was less than that of an ordinary car resting on four wheels only. The propelling apparatus was invisible to the passengers; the motor was boxed in completely; it was practically noiseless and free from danger. One man, not necessarily skilled, could drive the car, which could also be illumined at night by the electric current. Of course, the maintenance of the permanent way would cost less than where horses were used, and the charging stations would occupy less space than the stables.

Mr. W. R. Rowan could not agree with the two previous speakers. As far as he could gather, the contest at Antwerp was really between two combined cars, the electric car, and the steam-car which he had designed. Having been there some eight or ten weeks, he could bear testimony to the great care and trouble taken by the jury over this question. There was no doubt that the most taking car was the electric motor, but the whole question, from the first, hinged on one word—economy, and the question would turn out to be, Which was most economical, steam used directly in driving the car, or to produce electricity or compress air, which should then drive it? The electric car had all the advantages on its side as regarded appearance, and other qualities which might be desired in a motor for towns, but he thought it would be difficult for the jury to decide on the question of economy. There were four main difficulties which he thought it would take electricians some time to get over. The first was the transmission of the power. The use of a belt or chain was not generally supposed to be satisfactory, and he had his doubts about the worm-wheel. If electricians could discover a gearing which would enable them to work from a shaft running at 1,000, or even 500, revolutions a minute, those who employed steam would be very glad, because they could use it with small engines running rapidly. Such a style of engine was what naturally suggested itself for this purpose, but hitherto it could not be used on account of the difficulty in transmitting the power. The second difficulty was that of the accumulators; would they really last if knocked about daily in a tramcar? The trial at Antwerp gave very little information on that point, being short, straight, and level, so that they only had to be charged once a day. Had it been a line such as Mr. Reckenzaun mentioned, they would require charging four or five times a day. There was as yet no proof that the accumulators would stand, and if they had to be renewed even every year, the cost would be greater than that of maintaining a properly-constructed steam-engine. On a recent visit to Brussels he learned that the Company had voted 25,000 francs toward the establishment of a regular electric service on one of the lines there, in order to test this question; but he felt pretty confident that one or two years' trial would not lead to horses being superseded by electricity. The third difficulty was the charging of the accumulators. In running up steep grades, and with grooved rails, which added greatly to the friction, he believed the accumulators would have to be charged five times a day, which would be a practical difficulty. Lastly, if all these difficulties could be overcome, he doubted if they could work as cheaply as with steam direct, seeing that only 25 to 40 per cent. of the power would be utilized. The question of the power utilized, however, did not play an important part in tramway maintenance, the whole secret of mechanical tramway work would lie in having a motor powerful enough under certain circumstances, which would run very cheaply when it had little work to do, but which would work expansively, so that you could put on a second car and carry a large number of passengers when required; and up to the present, he ventured to say, there was nothing to compete with a simple form of steam-engine, where you had only to put a little more coal on the fire to obtain the necessary power.

Mr. Scott Russell thought it a pity Captain Galton had not given some information about the *Chemins de Fer Vicinaux*, because in Ireland that sort of railways was being begun. The other day he went over one of these lines, running partly on rails and partly along the road. On the road the locomotives were made to condense their steam; on the railway they worked in the ordinary way. The paper really had not much bearing on tramways in this country, because the conditions were so very different. The rail at Antwerp was an edged rail, in England they were grooved, which gave treble the resistance; and here we had heavy inclines, and in nearly every case the engine or horses had to be detached and turned round. Abroad, steam-engines puffed through the stations without any attempt at condensation; but here the local authorities were so strict that if there were any chance of arriving at perfect condensation, they would certainly insist upon it. He agreed with a great deal of what Mr. Rowan had said with regard to using steam direct; it must be a question of economy, and however much the public liked it, you would never find a tramway company adopting electricity or compressed air unless it paid them. From published results, it appeared that the cost of working with a detached steam-engine had been brought down to 3s. 3d. a mile, and, no doubt, with a combined car, it would be still less, as there would be less dead weight; with horses it was 4s. 8d., and compressed air, taking the results at Nantes, was 5d. a mile. He was rather a believer in compressed air, but did not think either the Mekarski or Beaumont system was likely to be successful, the dead weight being too great. The loss in the compression of air was so enormous, that unless the weight were reduced to a minimum, it could not be worked economically. A much more practical plan had been proposed in America, making a very light car with a low pressure of the air, and tubes carried along the center of the track, so that the car might be charged when it stopped, by means of a coupling similar to that of the air brake. With regard to electricity, he understood from practical electricians that the theoretical loss from the engines to the accumulators, from them to the dynamo, and from that to the rail, was something like 75 per cent. as a minimum, and he was afraid, unless accumulators were made much lighter, they would be found too heavy.

Mr. Scott Moncrieff said Captain Galton had pointed out what would be admitted more and more as time went on, that certain points, such as simplicity of construction, power of moving in either direction, applicability to existing lines, &c., were of vital importance, and especially that the motor should be self-contained for the purpose of locomotion in crowded thoroughfares. This was the first paper of importance on tramway traction independent of particular interests, and embracing the subject as a whole, and it was very satisfactory that it should be based on a series of practical trials such as those made at Antwerp. At the same time, he agreed that the trials were very unsatisfactory, for the reasons which had been pointed out. The absence of inclines and curves was a fatal objection, because the best motor at Antwerp might get a prize, on the strength of which it might be introduced in a place where it would prove a complete failure. He hoped that public attention being drawn to the matter would lead to similar trials being made in this country before long. Time did not allow of his referring at length to his own work in this direction, but he might say that his first series of experiments with compressed air was the means of inducing the Legislature to permit the use of mechanical traction on urban or suburban tram lines. In 1877 power was given, subject to the approval of the Board of Trade, for mechanical power upon a practically country line at Wantage, and also an urban line in the Vale of Clyde, and his evidence with regard to the success of compressed air led the Parliamentary Committee to recommend the passing of a bill sanctioning the use of mechanical power. In common with many others, he had been waiting for the ripening of public opinion with regard to the use of mechanical power other than steam. The pressure brought by the Board of Trade on inventors to produce something which would comply with their rules had been more or less relaxed, because no steam-engine had hitherto complied with those requirements all day long. During a certain period, or under certain conditions, the smoke and steam might be successfully suppressed, but after a certain amount of wear and tear it had been absolutely necessary for the Board of Trade requirements to be relaxed, if steam was to be applied to tramways at all. He could not speak as an expert in the matter of electricity, but its advantages, as regarded a self-contained vehicle of good appearance, were evident. Nothing surprised him more in Table No. II. than the extraordinary amount of fuel used by the compressed-air engine. It certainly bore no relation at all to the theoretical laws which bore on the conversion of energy from the boiler to the reservoir, and showed some egregious failure in the system. His own experience, as given in evidence in 1877, more nearly approached the Rowan engine, which stood at the head of the list for economy; but, as had been very properly said, if the proper motor were obtained, neither the public nor the companies would cut the matter so fine as to reject it on account of one or two lbs. of coal per train mile. He had urged before the Institute of Mechanical Engineers reasons for believing that in this particular case compressed air would be quite as economical as steam, the most obvious of these reasons being that a very large and powerful engine, embracing all modern improvements, and using a very small quantity of coal per indicated horse-power, might be employed. If such an engine only consumed 3 lbs. of coal, and there were a loss of 50 per cent. on the use of compressed air—which there ought not to be—you would get to practically the same economy as in the Rowan engine, at Antwerp, 5.42 lbs. Then the car itself, although somewhat heavier than an electric car, had still all the good qualities of a self-contained vehicle, capable of surmounting considerable inclines and going round sharp curves. He could not sit down without saying a word on the electric car described by Mr. Reckenzaun. He had long thought that the worm-wheel had been a too much abused mechanical appliance, and was not astonished to hear that the loss from friction at high velocities was much less than had been generally supposed. He should be interested to know how this worked in actual practice, but thought, from the appearance of the drawing, that it was too slight for the work it had to do.

Mr. B. Drake said that there were one or two points in connection with the Electric Power Storage Company, which he represented, which he should like to mention. They not only used accumulators at their own works, but had supplied them for trials elsewhere, and in practical working it was found that giving them the full charge, the efficiency in ampères was 75 per cent., and beyond that the loss in energy, expressed in watts, depended on the time at disposal to discharge them. When Mr. Reckenzaun tested them at the works, the power going into the accumulators necessary for each car was reduced to a minimum, and in those trials they were charged up rather quicker than they would be for lighting purposes, and there the efficiency was about seventy per cent. in watts. That experiment had been very carefully conducted, and might be depended upon. With regard to the duration, the same as had been in use for two years were now to be seen at the works; there was very little destruction of the plates, and what there was, was from mere mechanical shaking about. They were all perfectly ready, and if they were wanted to-morrow for an electric car could be put into regular work. M. Julien claimed a good deal in the way of production of local action by his special arrangement, but if one went into the causes of local action it would be seen that, if pure peroxide and pure lead were used, there was no necessity to have any local action at all. They had left batteries standing for six weeks fully charged, and at the end of the time the power was practically equal to what was put in. Whether they were discharged in one week or six weeks, the loss was hardly appreciable. The car at the works, from one cause or another, had not been used for some months, but still they were able to show it that day running without having been charged or touched for months. It had been stated on behalf of the compressed-air car, that stationary engines more economical than any which could be used on a car were applicable; this would also hold good in accumulators with this additional advantage, that in the case of compressed air, assuming that from the moment you started you had by some mechanical arrangement to get over the gradual decrease of power from the air chambers, whereas with accumulators there was practically no loss of locomotor force, from the time of starting until the time when they had gone so low that for the sake of sparing the plates you should not discharge them any further.

Mr. M. Holroyd Smith said a good deal had already been said which it was unnecessary for him to repeat, and he only needed to clinch the argument. Mr. Rowan and Mr. Reckenzaun had made comparisons between accumulators and steam traction, the former pointing out that the difficulty with accumulators was, that you had to take the power and convert it into electric energy, and then reconvert it into mechanical energy, and that there must be a loss in the transmission. With that he perfectly agreed; on the other hand, Mr. Rowan showed that the tests at Antwerp were unfair on account of the car running on a level without curves, and that where 2 horse-power would be sufficient on a level it would have to be raised to 8 on a gradient of 1 in 25. Now, he wished to prove that, especially in the case of accumulators, that meant an excessive demand on the stored energy contained in them, and he would venture to prophesy that Mr. Reckenzaun would find that by the manner in which he was now working the accumulators they would very soon be worn out, and he did not see how a tram line could be worked economically if the motive battery in the car lasted only six months. However, he believed he had absolutely solved the question which Captain Douglas Galton had put before them, viz., that, whether electricity could be applied with certainty to the propulsion of cars. He was now doing that, day in and day out, from morning to night, at Blackpool. He used electricity direct, and, therefore, there was no loss through the accumulators. The great question with regard to using electricity direct for street purposes was how to do it with safety to the public, and until he laid down this line it had not been done, because one rail had been used for the positive and the other for the negative current, or some side rail, which would be very dangerous to the traffic, had been applied. By conveying the electricity underground, and having a means of communicating with it in the car, it was possible to utilize it without any danger, either to the public or the traffic. That point had been most carefully tested by Major Armstrong. The Major felt a little trepidation at first, and it was not until holding his hand he touched the surface of the center channel and the surface of the rails at the same time, and could feel no possible shock, that he was satisfied of the fact. The cars were running every day except Sundays; the present being the off-season, there are only three, whereas, during the season there would be ten, and of course the same plant had to be put down, and the same electrician, and standing wages had to be paid as if the whole ten were running. It was, therefore, very unfair to take the present experience as a test of what could be done, because when the whole of the cars were running it only meant a little more coal in the engine; but even now the cost was only half that of horsing. On the same line, before the electric plant was completed, horses were employed, and being just at the close of the season they were obtained from omnibus proprietors at a very low price, but still it was double the cost of electricity.

Mr. Scott Moncrieff asked what was the actual sum paid.

Mr. M. Holroyd Smith said it was rather less than 6d. per mile for the horses, but they were now doing it at half that price; when the whole ten cars were running it would cost about 2½d. per mile, including depreciation and interest on outlay. The length of the line was over two miles, the steepest gradient 1 in 40, and the sharpest curve one of 48 feet radius, curve and gradient at the same place. The point he wished to insist upon was the advantage of driving tram-cars direct instead of using accumulators. He did not wish to argue against secondary batteries for tram-car work, for he thought they would serve a very useful and important purpose, by increasing the public confidence in electricity, and then they would be prepared to go the whole length, and use the direct current. At the same time, if you had to go up a gradient of 1 in 20 for a mile and a half, and another of 1 in 30 for two miles, as was the case in some places in Yorkshire, it required some pulling up, and unless the amount of accumulators in the car were doubled they would very soon be spent. Electricians knew that it was a very risky thing to quickly exhaust a secondary battery; you might charge them quickly if you liked, but it was a very awkward business to discharge them rapidly. The weight, therefore, would have to be increased, or their life would be shortened. Now, by his system, if the tram-car came to a hill, the man in charge only had to put on a little more resistance, and if necessary, the whole power generated at the station might be taken to send the car up the gradient. He could not only take the car, but could draw another behind it, loaded with passengers, up the steepest incline. Although they had been working through wet, wind, and snow, and the whole line had been deluged with sea water, they had been able to work with a loss from leakage of not more than the ampère of current.

Captain Douglas Galton, in reply, said he agreed with the comments which had been made on the line at Antwerp, which certainly did not represent those found in this country, but those who knew Antwerp would be aware that it was impossible to lay down a line there with steep gradients, and even sharp curves could not be made conveniently, having regard to other traffic on the boulevards. The full report of the jury would soon be published in a very complete form, and he hoped all persons would reserve their final opinion until then.

Mr. C. J. W. Jakeman writes:—I have heard Captain Douglas Galton with considerable pleasure, as his paper differs from many on this subject, in that it contains reliable figures and data, gathered from specially conducted public trials. I may say that my firm (Merryweather & Sons) was invited to take part in the trials, but after examining the road, decided that it would be no fair test of the practical working of the engines on ordinary town tramways, with grooved rails, and consequently did not enter the contest. From the figures given in the paper, it appears that Rowan's combined car was most economical in working, and that very little water (three quarters of a gallon per mile only) was required to make up loss; this was probably due to the fact that on a combined car, considerable roof-space is available for the condenser, and not to its construction; as in our experiments with plate condensers we have always found them inferior to tubulous ones, which we have finally adopted. With reference to this point, I may say that with our detached engines working on the North London tramways, with inclines of 1 to 20, only from 10 to 20 gallons of fresh water are required after a run of 11 miles.

The figures relating to the compressed air car are really astonishing, and, unless the principle of working air at high pressure is altogether wrong, as it possibly is, there must have been some very bad management in the working. The coke alone (3 lbs. per mile), used to warm the air, would have been more than half the quantity of fuel required to drive by steam direct.

The average heat value of well purified coal-gas at constant volume has been recently determined by M. Witz—*Ann. de Chim. et de Phys.*—as about 5,200 calories per cubic meter at 0 deg., and 760 mm. when the water formed is fully condensed. This value, got from a great variety of experiments with gas from different works, appears to make the generally accepted figure of 6,000 calories about 15 per cent. too high, and the calculation of gas motors is here concerned. The heat value of the gas from one and the same works varied in the course of a year from 4,719 to 5,425 calories, which was more than the variation between different works. The influence of temperature and external pressure was not perceptible. The operations for purifying gas diminish the heat effect sometimes as much as 5 per cent. The gas of the last hour of distillation is, *Nature* says—contrary to the usual view—less rich than that of the first hour. Dilution with oxygen lessens the heat value; but in dilution with air, curiously, no such effect is observed; the heat of combustion was the same with six or with ten volumes of air.

CORROSIVE EFFECTS OF STEEL ON IRON IN SALT WATER.

By J. FARQUHARSON, Esq.

Read before the Institution of Naval Architects.

At the meeting of this Institution last year, attention was drawn to this subject, and some particulars furnished of actual cases of rapid corrosion. The facts then stated were rather suggestive than conclusive that its origin was the steel combination, as there are other known causes of equally rapid corrosion where no steel is present. Large iron forgings, besides being liable to external influences, contain within themselves elements of decay as rapid as any then noticed. Such forgings are made up of numerous smaller ones, and after being welded up into one whole, they contain more or less magnetic oxide, which is as destructive as a like quantity of copper would be if placed in its stead; the well-known fissures, or deep seams which appear more or less in all rolled or forged iron when corroded by salt water, are wholly due to this cause; these fissures bear, in direction, a certain relation to one another, by which they are readily known when the actual case is before us, but not otherwise. Although the Admiralty practice does not involve combinations of iron and steel to any great extent, the question raised last year was considered of sufficient importance to test, by actual experiment, the results of which I am now permitted to bring before you. Before doing so, in order that the basis of the experiment may be clearly understood, it may be well to notice, briefly, another experiment, made two or three years ago for the purpose of testing the effects of surface oxide, or scale, on rolled mild steel. The two points which that experiment was designed to ascertain were, first, the amount of injury by pitting which the scale might cause in a given time when portions of the surface are unprotected by such scale; secondly, whether such scale action is likely to be permanent. The result went to show that there is practically no diminution at the end of six months' immersion in salt water; steel plates completely covered by scale in combination with a similar steel plate without scale, in some cases did not lose a single grain in weight. Second, the loss of weight, or work done by steel oxide, was found to be rather more than from a plate of copper of the same size. The experiment now about to be described was therefore undertaken with a full knowledge of these results, which account for much of the confusion and misapprehension which have arisen in cases where scale was neglected, and which show that in any case intended to test relative corrosion of metals, surface scale, or oxide must not be neglected; that care must be taken that the materials used are iron and steel, and nothing else, and that the surfaces be large enough to give a good average result. In the present case, plates of iron and steel of equal size, with an aggregate surface of 48 superficial feet, were used. After having the scale completely removed by dilute hydrochloric acid, they were singly weighed, marked, and placed in a grooved wooden frame, parallel and one inch apart, iron and steel alternately. The first, third, and fifth pairs were electrically combined by straps of iron at the tops, the second, fourth, and sixth pairs being left unconnected, and therefore each plate of which was only subject to ordinary corrosion, as if no other metal existed. The whole series, so arranged, were placed in Portsmouth Harbor, and left undisturbed for six months, when they were taken up and again weighed. The loss of each plate was found to be as under:

		Oz.	Gr'ns.
Steel	combined	0	427
Iron	combined	7	417
Steel		3	340
Iron		3	327
Steel	combined	0	297
Iron	combined	7	77
Steel		4	0
Iron		3	190
Steel	combined	2	337
Iron	combined	6	0
Steel		4	157
Iron		4	57

From the above it will be seen that the three iron plates combined with steel lost 21 ounces 57 grains; that the three similar iron plates not combined lost only 11 ounces 137 grains. The plates were identical in size, and all cut from the same sheet, the effect of combination with steel being to nearly double the loss of weight. The proof that the great excess of loss was not due to anything in the plates themselves will be clearly seen by comparing the combined and uncombined steel plates thus: The three combined with iron lost only 4 ounces 187 grains; the three uncombined lost 12 ounces 60 grains, or nearly three times as much as those protected electrically by the iron. These two facts taken together, viz., iron combined with steel invariably lost more, and that steel so combined lost less, prove to a demonstration that electrical action existed. The difference in such loss of weight is a measure of the amount of such action from which it would be easy to draw wrong conclusions. One thing may be inferred, viz., that in this particular case about two-thirds of the electrical energy of the combination was given up in reducing the metal, and the other one-third in the intervening liquid. Taking the distance apart into consideration, it will be seen that the energy was considerable. The laws of electro-chemical action are brief, simple, and invariable, but the results are so modified by conditions which interfere in practice that a clear appreciation of them is necessary in in each particular case. It would not be safe to infer that if these plates had only been one-fourth the distance apart, the loss would have followed the well-known law, because, in such a case it is probable that the action would soon have been arrested by the formation of rust between the plates; on the other hand, if the iron plates had been protected, except a patch in the middle, by waterproof material, all other things remaining the same, it is quite certain that the result would have been serious injury to the plate by pitting of the exposed part, on which a very large portion of the energy in such a case would have been concentrated. Again, had the plates been placed edge to edge and contact maintained, the iron would certainly have suffered much on the edge next the steel. Before leaving this part of the subject, a word of explanation with reference to a difference which may be noticed in the relative loss of the third pair of combined plates is necessary, in which case the steel lost more and the iron less than in other similar pairs. The probable cause of this is that the connection at the top was less perfect than it should have been, and that, in consequence, rust formed between the connecting strap and the plate, which after a time arrested the electrical energy and reduced it to a case of simple corrosion. With this exception, which is not a large one, the results are fairly uniform, when judged in the light of local influences which may exist in the individual plates.

The main object of this experiment was to test the effects of combinations of iron and steel, and the lesson taught is to either avoid altogether such combinations, or to take care to so modify the conditions as to minimize the injury to the iron; but you will observe that the arrangements in this experiment are such that the results may throw some light on a still more important question, viz., the relative endurance of iron and steel when freed from injurious combinations. The already extensive and still growing use of steel makes this a matter of very great importance. Assuming that the unconnected plates of steel and iron represent the normal loss of each under ordinary and equal conditions, they approximate so closely that the endurance may be considered as practically the same, and this result agrees with that obtained from other and more extensive tests previously made for the Admiralty, and which formed the basis and justification of the use of steel instead of iron in naval construction. In the present experiment the unconnected plates had an aggregate surface of 12 superficial feet each metal. The total loss of weight was—iron, 11 ounces 137 grains; steel, 12 ounces 60 grains; difference in favor of iron on the whole surface, 360 grains weight, or 30 grains per foot superficial, which is inconsiderable. A careful examination of the steel plates in this and other cases, after immersion, convinces me that these results (satisfactory as they may be when taken in conjunction with the other advantages of steel) are neither as good as they might be, or as they would be, if the importance of uniformity were recognized, and the ingredients thoroughly mixed, as they should be in the process of manufacture. In almost every plate there are evidences of local action between one portion and another—a sure indication that the manganese is not evenly diffused throughout. The plates used in this experiment are here, and we advised all interested to examine them and judge for themselves. In a former case, in which the surfaces before immersion had been finished bright by fine filing, the marks could be seen, after six months, on some parts, whilst other parts of the same plate were well corroded. In the present case the plates were not so prepared, but there are equally clear evidences of the facts observable. I commend this matter to the attention of steel-makers and steel-users, who are both interested. It has been said that manganese is difficult of diffusion, but if its importance as affecting the durability of the steel is recognized, means would soon be found to improve it. Knowing the facts stated above, on a recent visit to steel works I took careful note of the practice, which was as follows: The furnace was tapped, and as soon as the molten steel began to run into the ladle, two men, each with a shovel, began to throw the ferro-manganese into the ladle, and this they continued to do until the steel was all in; no steps whatever were taken to mix by stirring or agitation. In such a process the wonder is that the results are no worse than they are found to be. When the ingredients are thorougly mixed, there is good reason to believe that the endurance of steel, as regards corrosion, will not only be equal to the best iron, but far superior, as it ought to be; and the time may not be far distant when consumers may find a ready means for detecting inequalities which will help to secure attention to this important matter.

DISCUSSION.

Mr. Mesham. My lord, I thought, perhaps, it would interest the meeting—I will not detain you long—to show you samples of iron treated by a process whereby this magnetic oxide is produced by artificial means, where a portion of the plate has stood two years in continuous submersion in salt water. I have only to add that I hope the time will soon come when this process will be largely used for the purpose of protecting steel and iron ship plates. I have this piece of iron, which is at anyone's disposal, and I think you will all admit there is not a particle of rust upon it of any kind.

Capt. Watt (of Liverpool). My lord, I have a little experience which points to exactly the reverse of that. The conditions are not exactly the same, because the vessel that I sail in was employed in salt water. The screw was worn away on the leading edge, and was patched with mild steel. We found that the mild steel was eaten away by the cast iron. In that case the steel suffered far more than iron.

Mr. B. Martell. My lord, I have only a few words to add, and these are in corroboration of what Captain Watt has said. It only shows the mystery that underlies all these things. I think we are very much indebted to the Admiralty for placing the results of their experiments before us in this way. The question of steel for ship-building purposes is now a question of very great importance, not only to the Admiralty, but to the mercantile marine also, and they are not only looking to the quality of it, and to these mysterious symptoms which are said sometimes to occur, but also to its durability. That is a matter that is occupying the very serious attention of many shipowners at the present time. Any information that can be brought before them in the way of real practical experience of this kind is a matter of great importance. As I said before, we are very much indebted to the Admiralty for placing before the public any experiments they make in this way. I would remark, that in the case of a ship built some little time ago (a steel vessel that was riveted with iron rivets), I had an opportunity of seeing her after she had been running twelve months, and I then found that the steel plates in the immediate proximity of the iron rivets had deteriorated very considerably beyond what the iron rivets had; the rivet points protruding some distance beyond the steel plates, while the steel around the iron rivets had deteriorated very considerably. I am sorry that the builder of that ship—Mr. Raylton Dixon—is not here; he was here this morning to make some remarks upon that point. That appeared to me to show that this deterioration was not due to mere corrosion, but was probably due to galvanic action, from the rapidity with which it occurred, and from its being in so many places immediately round the rivet points. Although we see the plates placed before us here, and can place implicit reliance on the experiments made by Mr. Farquharson, showing the results to be almost invariably that the iron has suffered most from this action, yet, in the case I have mentioned, the steel had deteriorated more than the iron.

Mr. Barnes. Mr. Martell, would you kindly inform the meeting what the nature of the iron rivets was? Was it Bowling, Lowmoor, or ordinary Staffordshire?

Mr. Martell. I wish, as I said before, Mr. Dixon was here, but I have reason to believe that it was Continental iron—I think so—because I know at that time he was importing a large quantity of iron rivets from the Continent.

Mr. Barnes. That is very important.

Mr. W. Denny. I think the paper Mr. Farquharson has brought before us is one for which we have every reason to be thankful, but it is not one that can be easily discussed offhand, because, as Mr. Farquharson has pointed out, there are many matters in it, especially these extraordinary-looking lines in the specimens (pointing), which are rather suggestive than capable of solution at this meeting, or perhaps for several meetings to come. There are many points about the corrosion of steel, and also the corrosion of iron by steel, that are really worthy of serious consideration. Mr. Martell has given his experience where iron rivets corroded steel plates. My firm has had an opposite experience. We built for the Peninsular and Oriental Company their first steel steamer, the *Ravenna*, and I drew the attention of the Institution last year to the fact that, while the whole of the hull of the *Ravenna* was steel and the rivets were steel, the only portions that were iron were the forgings and certain covering plates in the rudder—the plates covering the distances between the pintles, the actual rudder plates being steel. What we found in the case of the *Ravenna* was this, that there was a large corrosion (which you can see for yourselves, because here is a cast of it) at the upper rudder band of the *Ravenna's* rudder-post. That corrosion goes in for nearly $\frac{3}{16}$ of an inch, pitting into the iron rudder-post. There was a further corrosion, although not so serious, in some portions of the iron rudder, and there was some little corrosion also in the iron covering plates of the rudder. There was no corrosion whatever in the steel plates of the rudder, showing that whatever effect was produced affected simply the iron and nothing else. While I do not think we can gather anything very conclusive from this paper, or from the experience Mr. Martell, my own firm, and the Peninsular and Oriental Company have had, with regard to the cause of the actual effects produced, there is one conclusion we can draw from them, that it is a very unsafe thing to put any other metal with steel under water. On that account my firm have adopted the practice, in all our steel steamers, of using only steel rivets and steel forgings. Since we have done that we have not, so far, observed any of these defects. There is another point of importance on the subject of corrosion: I had occasion to examine the bottom of a steel steamer lately, and, among other parts, the inlet where the water was taken in for the condenser. The inlet was covered by a large brass plate with holes in it. When that brass plate was removed we were perfectly astonished at the corrosion which had gone on, and which had eaten down into the steel to the extent of $\frac{3}{16}$, and I examined the other inlets in the same ship, and found similar corrosion. I would, therefore, call attention to the serious danger not only of bringing together iron and steel in a steel ship, but also of placing brass upon the bottom of a steel ship.

A member. May I ask Mr. Denny whether the rudder bearings were bushed with metal in the case of the *Ravenna?*

Mr. Denny. I think it was lignum-vitæ.

Mr. W. W. Rundell. My lord, I should like to ask a previous speaker a question with regard to the example showing corrosion of the plates instead of the rivets; I should like to ask in what sea the vessel sailed, in what harbor she was lying, and under what circumstances these apparently curious occurrences happened. I am not surprised to hear that two pieces of iron may mutually act on one another electrically, because I remember once having a battery composed entirely of plates of iron cut from the same sheet, and therefore of the same chemical composition, but yet these plates of iron formed a most powerful battery, and for this reason, that the plates in each pair were placed in opposite electrical conditions by being immersed in different fluids with a thin diaphragm between; one was excited by nitric acid, and the other was excited by an alkaline solution. They were thus placed in very different conditions, although they were plates from the same material. If we knew the character of the water in which the vessel in question had been lying it would throw some light on the particular circumstances of the case. I should like to ask if it is known in what sea or harbor that vessel had been lying. The mysterious symptoms would probably disappear if the facts were clearly stated.

Mr. Denny. With reference to which ship—the question of the corrosion of the iron by the steel?

Mr. Rundell. I referred to the case mentioned by Mr. Martell—the vessel built by Mr. Dixon.

Mr. Martell. The liquid in which these vessels were was salt water.

Mr. Manuel. May I ask Mr. Martell if he knows from his own experience the action of the iron rivets used in riveting on the mild steel shell plates of the steamer *Ethel*, built in 1878? It so happened that it was a new departure to construct ships of mild steel in the district where I had the honor to serve as engineer surveyor to Lloyd's Registry, and the rivet boys in heating the steel rivets destroyed them. It was then thought under these circumstances, until we found out the cause of the steel rivets becoming weak and unfit, to substitute iron rivets instead of the steel rivets, and as this vessel is periodically surveyed by Lloyd's Registry, Mr. Martell may be able to tell us now, from the time that steamer has been running in salt water, whether the iron rivets are affected by the steel plates, or the steel plates by the iron rivets. That was in 1878. With regard to Mr. Denny's mention of a steamer belonging to the Peninsular and Oriental Company which had steel plates in the rudder, the frame of which was formed of iron, it will be interesting to know, when that steamer returns, the result of putting in iron rivets instead of steel to keep these plates close again, which Mr. Denny says were the cause of the corrosion of the iron. I shall be able to give at some future time some more information with regard to this. The steel rivets which had become loose in the rudder were replaced by iron rivets. I am not quite of the same opinion, and I do not think that there is any such action as Mr. Denny seems to expect. It is very difficult and a very critical thing in constructing a steel steamer to get everything of steel throughout. I do not think if the steel and the iron are faithfully put together there will be very much to fear from the action of the metals. With regard to the corrosion of steel on screw propellers mentioned by Captain Watt, I have had a little experience, and I have not found that even metal such as brass or Muntz metal when put on steel blades has such a bad action as has been stated. For instance, the steamer *Lombardy* has Vickers' steel blades. I think she is at Messrs. Caird & Co.'s yard at present, but she was built by Messrs. Denny & Co. These steel blades corroded so rapidly—in fifteen months or less—that it was found necessary to do something to protect them, and we sheathed them at ends of blades with brass plates with good results, and these blades have now been running for five or six years, and are intact still. Since that I have used this mild steel of twenty-six tons to the square inch on behalf of the Peninsular and Oriental Company for the construction of some propeller blades on account of its superior strength, but again they were subject to this same corrosive action at blade points by salt water. We found that while we got steel blades to stand as regards strength, they corroded very rapidly in one voyage of three months, and to protect them I covered them with brass sheathing, and we have found this to be a marked success; the blades have not deteriorated further, although sheathing was put on in a hurried manner in dry dock, as close as it could be done by workmen. It stands well, and I believe it will be successful, and that we shall be able to keep on the steel blades without having to renew them by such an expensive method as new ones every eighteen months or two years, which has been the case with some of the steamers in the Liverpool mail service. I think Messrs. Vickers fully agree with what I say. They have seen the blades after they had run two voyages, and are quite pleased with the result of putting brass on to steel to prevent corrosion of steel by salt water.

Mr. W. H. White. My lord, I will say a word in reply to the observations of Mr. Denny. Mr. Denny said, as I understood him, that it was undesirable to have brass under water fittings in ships.

Mr. Denny. Yes.

Mr. W. H. White. In the Admiralty service we always have brass under water fittings, and the bottom plates do not suffer in the way Mr. Denny has experienced, because we fit protectors of some other metal on them, which will suffer from the action of the brass, and leave the skin of the ship intact. Of course, the principle of protection may be carried further. I will only add that I think the value of this paper will appear on closer reading, but we have here really a large laboratory experiment rather than an example of common practice. We have not the surface protected by anticorrosive paint at all. It is quite possible the results attained here with bared surfaces are exaggerations, as I think Mr. Farquharson will tell us, as compared with any thing we could expect to get in the way of wear in actual practice on the bottoms of ships protected by paints. In the experiments the plates had this bare surface, and were immersed in sea water and fully exposed.

Mr. Farquharson. My lord, first let me refer to a remark made by Mr. White before I forget it. It is quite true that these experiments were made expressly to put the two metals on an equal footing, and under the worst conditions possible. The object of it was to ascertain what effect steel had on iron, or iron on steel; therefore, it was necessary, as it is in all experiments, to carefully provide against any extraneous circumstances that would influence the result. Now, with regard to Capt. Watt's observations, I need only say that those circumstances were different, and cannot be judged of from anything you see here or what I have said. Mr. Martell has made some interesting remarks with regard to what occurred around iron rivets. That, again, is a case that I should have very much liked to have seen, because there are many circumstances to be taken into consideration that might modify the results. These results follow, and will follow, all similar arrangements placed as that was, but there are many circumstances, I need hardly tell you, that influence it very much. The formation of an oxide on one metal less exposed to the wash of the water than the other, at once changes the direction of the current, and would, therefore, throw the action on the opposite metal. A remark has been made with regard to an iron battery, which leads me to say that we expect, in all wrought iron, conditions which would produce almost anything that you like, provided that you only let us arrange it in the order that will produce that. I think, sir, I need hardly trouble you with any further remarks on the matter, as I think the facts are not challenged.

The President. I am sure you will allow me to convey, not only our formal thanks to Mr. Farquharson, but also will allow me to point out to you that we are under a special obligation to Mr. Farquharson, because he is not a member of our institution, and he has conducted the experiments with the greatest care. I am sure you will see from his paper, and gather from his remarks likewise, these valuable experiments, which, I venture to think are of national importance to all users of steel. Therefore you will allow me to convey a special vote of thanks to Mr. Farquharson for his paper, and for the ability with which he has conducted for the Admiralty, and the public in general, these most valuable experiments.

The mortar used for the external brick facing of the Forth Bridge piers below water, says *Engineering*, consists of one part of Portland cement and one part of sand lightly ground together in a mill with salt water. The average tensile strength of samples taken from the mill is 365 lbs. per square inch at one week, and 510 lbs. at five weeks after mixing.

EXPERIMENTS TO DETERMINE FRICTIONAL RESISTANCES OF RAILWAY TRAINS.

By C. H. HUDSON.

Journal of the Association of Engineering Societies.

This paper is descriptive of a series of experiments made by the writer a few years ago for the purpose of furnishing some evidence in a pending lawsuit between two railroad companies. The questions studied were the resistances of the trains and the powers of the engines. The subject was not a new one, the ground having been gone over many times; but possibly the treatment of it in this case may vary somewhat from other methods, as shown by published records. The means adopted were such as we deemed best to furnish us with the information needed at the time, and, though somewhat crude, the end was attained. The experiments themselves were not as extended or varied as they probably would have been, had any other use been expected of them. Those relating to the resistance consisted in ascertaining in what time and distance a train of a given weight, and moving at a known speed upon given grades, would stop, and from the data obtained we have made our calculations.

The time was measured by watches usually used for timing horses, and to be sure that no mistakes were made they were in the hands of several people, so that in no case did less than two people observe the times taken. Distances were accurately measured in the usual way. No special pains were taken to select engines or cars in good order. The latter were taken from the side track as they chanced to stand, loaded with coal, and accurate weights taken. The engines, in the same way, were taken as they came, and were at liberty; but they were in good condition, and of the ordinary "American" type, of dimensions hereafter shown. The cars were ordinary flat-bottom coal-cars, or gondolas, with thirty-three-inch wheels, three and one-half by six and one-half journal, brass bearings, and lubricated with black oil of rather inferior quality.

The dimensions and weights of the engines as used, and of the cars, with their loads, are as follows:

Engine No. 48.—Cylinders, 17 in. diameter, 24 in. stroke; driving wheels, 62 in. diameter, four coupled, with four-wheel truck, "American" style; tender on two four-wheeled trucks. Weight of engine on trucks, 27,450 lbs. (as it came in from the road, with about three-fourths tank water and one-half tank of coal); weight on driving wheels, 46,300 lbs.; total weight, 73,750 lbs.; tender three-fourths full of water and one-half full of coal, 40,900 lbs.

Engine No. 47.—Same as 48.

Position in Train and Weight of Cars Used in Experiments, Numbering from South End.

Position.		Number.	Gross Weight.
1	....	2,057	47,700
2	....	2,315	47,900
3	....	167	47,100
4	....	2,189	50,700
5	....	987	48,200
6	....	2,061	48,200
7	....	2,015	49,700
8	....	405	47,700
9	....	2,165	48,000
10	....	203	44,900
11	....	285	48,600
12	....	977	47,400
13	....	855	48,900
14	....	2,103	48,800
15	....	205	53,400
16	....	2,049	43,500
17	....	523	48,200
18	....	2,073	47,800
19	....	493	47,700
20	....	383	47,100
21	....	907	48,000
22	....	677	44,000
23	....	2,171	49,100
24	....	2,287	48,000
25	....	325	48,500
25	....	495	49,000
27	....	311	51,200
28	....	2,295	51,000
29	....	351	49,400
30	....	2,025	47,600

Engine No. 63.—Cylinders, 17 in. diameter, 24 in. stroke; driving wheels, 58 in. diameter, four coupled, with four-wheeled truck; tender on two trucks, four wheels each; weight, engine truck, light, 23,740 lbs.; 3 gauges water, 26,557 lbs.; weight on drivers, light, 40,960 lbs.; 3 gauges water, 46,563 lbs.; total weight, light, 64,700 lbs.; 3 gauges water, 73,120 lbs.; tender weight, light, 23,100 lbs.; full of water, 42,200 lbs.; full of water and $4\frac{1}{2}$ tons coal 51,200 lbs.

Experiment 1.

Engine 48, weight	73,750 lbs.
Tender, "	40,900 "
15 cars (1 to 15 inclusive), weight	727,200 "
Total	841,850 lbs.
Length of train, including engine	533 ft.

Train got under motion on level, and steam shut off at foot of 52.8 up-grade, on tangent.

Speed measured by time taken to pass a base line 400 feet long:

Seconds passing base	23.35	
Speed per second	17.17	ft.
" minute	1,028	"
" hour	11.70	mls.
Train ran by momentum	538	ft.
Time used (estimated)	63	sec.

Very light wind on right side, nearly at right angles to train.

Unfortunately, in the first six experiments no note was taken of actual time used in the stop, and we have to estimate it. We do this on the theory that the retarding force is constant (probably not exactly true in this case).

We use the formula $T=\frac{2S}{V}$, in which T=time; S=space, and V=velocity at time steam is shut off. This gives $T= =\frac{1076}{17.17}=63$. The estimated times mentioned hereafter are calculated in this way.

Now, to estimate the resistance, which is the retarding force, we will again assume that it is constant. This would be true if the train was all on the 52.8 grade; but in fact it commences to enter that grade just when steam is shut off, and when the train is on a level. We take V=velocity=17.17; S=space run =538; T=time (estimated)=63. As our three items do not exactly correspond, we shall not get an exact result, but will take the three formulas for the momentum at end of first second (working from the other end, and supposing that our body moves from a stand with increased velocity till it reaches that at which, in our experiments, we start):

$$\text{First F., momentum}=\frac{V^2}{2S}=.27399$$

$$\text{Second F.,} \quad =\frac{2S}{T^2}=27110$$

$$\text{Third F.,} \quad =\frac{V}{T}=.27270$$

.81779

Average, .27259

The momentum of a body in a uniformly accelerated motion at the end of the first second varies as the velocity, and the velocity varies as the power causing the velocity or motion. In case of a body affected by gravity we have, the power (weight of body)=1, and momentum 32.

In the case of our experiments we have the momentum .27259. Upon the basis of above relations we can take the following proportions: $1 : 32 : : x : .27259$, x being the measure of amount of force causing the acceleration (or retarding), which gives=.27259.

Reduce, and we have $x=.008519$. Now, for one ton we have $.008519\times 2{,}000 =17.038$, which gives the resistance per ton causing the train to stop, providing the force acted uniformly.

As a matter of fact, the train all stood on a level save the engine itself; the tender was on the level.

The movement was 538 feet, and gravity affected the engine during the entire movement, and the tender all but its length, and so on.

On next page is a table of the weights of engines, tenders and cars, in tons, with the distance they moved on the 52.8 grade, where gravity would retard the movement at 20 lbs. per ton.

Column 1 shows engine and cars as in train. Column 2 shows weight in tons. Column 3 shows distance moved on 52.8 grades. Column 4 shows weight multiplied by distance.

1.	2.	3.	4.
Engine	36.9	538 feet.	19,852.2
Tender	20.4	518 "	10,567.2
1	23.9	486 "	11,615.4
2	23.9	454 "	10,850.6
3	23.6	422 "	9,959.2
4	25.3	390 "	9,867.0
5	24.1	358 "	8,627.8
6	24.1	326 "	7,856.6
7	24.8	294 "	7,291.2
8	23.9	262 "	6,261.8
9	24.0	230 "	5,520 0
10	22.5	198 "	4,455.0
11	24.3	166 "	4,033.8
12	23.7	134 "	3,175.8
13	24.4	102 "	2,488.8
14	24.4	70 "	1,708.0
15	26.7	38 "	1,014.6
	420.9		125,145.0

125,145×20 lbs. (due gravity)=2,502,-900.

Now, our estimated resistance to the ton, as given (p. 256), was 17.038 lbs. per ton.

17.038×420.9 (weight of train) ×538 feet (distance moved) 3,858,144
From which deduct am't due gravity. 2,502,900

We have 1,356,244

Divide by 538 (distance moved) we have 2,519.04; again divide by 420.9 (total tons) we have 5.984 lbs. for the resistance due other causes than gravity.

Experiment 2.—Same train, place and conditions.

Time passing base	28.9 sec.
Speed per second	13.83 ft.
" minute	830 ft.
" hour	9.43 m.
Distance run	403 ft.
Time (estimated)	58.3

As before, $V=13.83$, $S=403$, $T=\frac{2S}{V}=$ $=58.3$ (estimated).

Then,

$$F=\frac{V^2}{2S}=.2373$$

$$F=\frac{2S}{T^2}=.2371$$

$$F=\frac{V}{T}=.2372$$

Average, .2372

As before, 1 : 32 : : x : .2372, and $x=$ .0074125, or per ton .0074125×2,000= 14.825.

	Tons.	Distance on 52.8 grade. Feet.	Tons × Distance.
Engine	36 9	403	14,870.7
Tender	20.4	383	7,813.2
1	23.9	351	8,388.9
2	23.9	319	7,624.1
3	23.6	287	6,773.2
4	25.3	255	6,451.5
5	24.1	223	5,374.3
6	24.1	191	4,603.1
7	24.8	159	3,943.2
8	23.9	127	3,035.3
9	24.0	95	2,280.0
10	22.5	63	1,417.5
11	24.3	31	753.3
12	23.7	0	....
13	24.4	0	....
14	24.4	0	....
15	26.7	0	....
	420 9		73,328.3

73,328 3×20 (effect of gravity on 52.8 grade) 1,466,566

420.9 (tons) ×403 (distance) ×14.825. 2,514,656
Subtract amount due gravity 1,466,566

We have 1,048,090
Divide by 403 (distance) 2,600.72
Divide again by 420.9 (tons) 6.45
equals resistance from all other sources besides gravity.

Experiment 3.—Same train, place and conditions:

Time passing base	40 sec.
Speed per second	10 ft.
Speed per minute	600 "
Speed per hour	6.81 m.
Distance run	234 ft.
Time used (estimated)	47 sec.

As before,

$$V=10 \quad T=\frac{2S}{V}=47 \text{ sec.}$$

And again :

$$F=\frac{V^2}{2S}=.21367$$

$$F=\frac{2S}{T^2}=.21186$$

$$F=\frac{V}{T}=.21256$$

Average, .21269

As before, 1 : 32 :: x : .21269. x= .0066465, or, per ton=.0066465×2000= 13.39 lbs.

	Tons.	Distance on grade. Feet	Tons. × distance.
Engine......	36.9	234	8 634.6
Tender	20.4	204	4,161.6
1.... ..	23 9	172	4,110.8
2..........	23.9	140	3,346.0
3..........	23.6	108	2,548.8
4	25.3	76	1,922.8
5	24.1	44	1,060 4
6..........	24.1	12	289.2
7	(as before)		
8..........			
9..........			
10..........			
11..........			
12..........			
13..........			
14....			
15..........			
	420.9		26,074.2

26.074.2×20 (effect of gravity)....	521,484
420.9 (tons)×13.39 (estimated momentum) ×234 (distance).	1,318,789
Due other resistance than gravity..	797,305
Divide by 234 (distance)..........	3,407.3
Divide again by 420.9 (tons).......	8.09

equals resistance per ton other than gravity.

Experiment 4.—Same train, place and conditions:

Time passing base..............	35.4 sec.
Speed per second................	11.3 ft.
Speed per minute................	678 ft.
Speed per hour..................	7.70 m.
Distance run....................	316 ft.
Time used (estimated)...........	56 sec.

As before,

V=11.3 S=316 feet T=56 seconds.

$$F=\frac{V^2}{2S}=.20204$$

$$F=\frac{2S}{T^2}=.20153$$

$$F=\frac{V}{T}=.20178$$

.60535

Average, .20179

Then, 1 : 32 :: x : .20179. x=.006306, or, per ton, .006306×2000=12.61 lbs.

	Tons.	Distance on grade. Feet.	Tons × distance.
Engine.......	36.9	316	8,500.4
Tender.......	20.4	296	6,038.4
1............	23.9	264	6,309 6
2............	23.9	232	5.544.8
3............	23.6	200	4,720.0
4............	25.3	168	4,250.4
5............	24.1	136	3,277.6
6......... ..	24.1	104	2,506.4
7	24.8	72	1,785.6
8............	23.9	40	956.0
9............	24.1	8	192.8
10............	(as before)		
11............			
12............			
13............			
4............			
15............			
	420.9		44,082.0

44,082×20 (effect of gravity)........	881,640
420.9 (tons) ×12.61 (estimated resistance) ×316 (distance)	1,677,185
Resistance other than gravity.......	795,545
Divide by 316 (distance)............	2,517.55
Divide by 420.9 (tons)...	5.95 lbs.

equals resistance other than gravity.

Experiment 5.—Same place, time and conditions:

Time passing base...............	25.6 sec.
Speed per second................	15.62 ft.
Speed per minute............	937 5 ft.
Speed per hour......	10.65 m.
Distance run	495 ft.
Time (estimated)................	63 sec.

Then,

V=15.62 S=495 T=63.

$$F=\frac{V^2}{2S}=.2464$$

$$F=\frac{2S}{T^2}=.2488$$

$$F=\frac{V}{T}=.2479$$

.7431

Average, .2477

Then, 1 : 32 :: x : .2477. x=.00771 ; .00771×2000=resistance per ton=15.42 lbs.

	Tons.	Distance on grade. Feet.	Tons × distance.
Engine	36.9	495	18,265.5
Tender	20 4	475	9,690.0
1	23.9	443	10,587.7
2	23.9	411	9,822.9
3	23.6	379	8,944.4
4	25.3	337	8,526.1
5	24.1	305	7,350.5
6	24.1	273	6,579.3
7	24 8	241	5,976.8
8	23.9	209	4,995.1
9	24.0	177	4,248.0
10	22.5	145	3,262.5
11	24.3	113	2,745.9
12	23.7	81	1,919.7
13	24.4	49	1,195.6
14	24 4	17	414.8
15	26.7	0	......
	420.9		104,524.8

104,424.8 × 20	2,090,496
420.9 (tons) × 495 ft. × 15.42	3,212,687
Due other than gravity	1,122,191
Divide by 495	22,669
Divide again by 420.9	5.38 lbs

resistance per ton other than gravity.

Experiment 6.—Same train and time. Train entirely upon a 52.8 grade, but engine at beginning of 2-degree curve to right when shut off, train on straight line.

Time passing base (300 ft.)	18.10 sec.
Speed per second	16.57 ft.
Speed per minute	994 ft.
Speed per hour	11.33 m.
Distance run	321 ft.
Time (estimated)	39 sec.

$V=16.57 \qquad S=321 \qquad T=39$

$$F=\frac{V^2}{2S}=.42767$$

$$F=\frac{2S}{T^2}=.42208$$

$$F=\frac{V}{T}=.42487$$

1.27462

Average, .42484

Then, 1 : 32 :: x : .42484. x=.013277; per ton=.013277 × 2000=26.554 lbs. As whole train was on 52.8 grade, the resistance due gravity =20 lbs.; resistance other than due gravity, 6.554 lbs.

Experiment 8.—The trial was made upon level and straight track. Track was in fair condition, iron rail put up with sand (as was the track where all these experiments have been made). The joints were down somewhat, and the whole bed was much more elastic than if put up with coarse gravel or stone. Engine 47. Cars 16 to 30, inclusive.

Base line	300 ft.
Time passing base	17 sec.
Speed per second	17.65 ft.
Speed per minute	1,059 ft.
Speed per hour	12.08 m.
Distance run	1,500 ft.

When engine struck down grade, train was then running at speed, per second, 8.10 ft.; per minute, 4.86 ft.; per hour, 5.52 miles. Light wind on right-hand side and a little in rear. Train going north.

Now, to estimate the time:

T, the train is in passing the 1,500 ft.

8.1 T=the space passed due the velocity at end; and, 1,500−8.1 T=the space due the retarded velocity.

Then,

$$T=2S=\frac{2(1500-8.1T)}{9.55}$$

Reduce, and T=116.5.

We before had

$$S=1,500-8.1T=1112.7$$
$$V=9.55.$$

Then,

$$F=\frac{V^2}{2S}=.08196$$

$$P=\frac{2S}{T^2}=.08368$$

$$F=\frac{V}{T}=.08368$$

Average, .08311

Then, 1 : 32 :: x : .08311. x= .0025973; .0025973 × 2000=5.194 lbs.= resistance per ton.

Experiment 9.—Same time, place and conditions:

Time passing base (300)	26.1 sec.
Speed per second	11.48 ft.
Speed per minute	689 ft.
Speed per hour	7.82 m.
Run	1,272 ft.
Time (estimated) going north	221 sec.

V=11.48 S=1,272 ft. T=(est.)221 sec.

$$F=\frac{V_2}{2S}=.0518$$

$$F=\frac{2S}{T_2}=.0521$$

$$F=\frac{V}{T}=.0519$$

.1558

Average, .05193

Then, 1 : 32 :: x : .05193. x=.001623; for one ton .001623×2000=3.246 lbs.= resistance per ton.

Experiment 10.—At same place as 8 and 9. Engine 63, weight 60 tons; cars 16 to 30, weight 360 tons; total, 420 tons; length of train, 533 feet.

Time passing base (300)	30.4 sec.
Speed per second	9.87 ft.
Speed per minute	592 ft.
Speed per hour	6.73 m.
Run, north	1,013 ft.
Time, actual	185.5 sec.

Time estimated as 205 seconds. Light wind on side and toward rear.

V=9.87 S=1,013
T (actual)=185.5.

$$F=\frac{V^2}{2S}=.04852$$

$$F=\frac{2S}{T^2}-.05888$$

$$F=\frac{V}{T}= .0532$$

1.16061

Average, 0.5353

1 : 32 : : x : .05353. x=.001673; for 1 ton=.001673 × 2000=3.346 lbs.=resistance per ton.

Experiment 11.—Same place, time and train. Same conditions, except that train moved south over same ground, the engine being in rear, and same light wind tending to retard, if enough in rear (front) to have any effect.

Time passing base (300)	33.8 sec.
Speed per second	8.87 ft.
Speed per minute	532.2 ft.
Speed per hour	6.04 m.
Run	592 ft
Time, actual	132.5 sec.
" estimated	133.5 "

V=8.87 S=592 T=132.5

$$F=\frac{V^2}{2S}=.06645$$

$$F=\frac{2S}{T^2}=.06744$$

$$F=\frac{V}{T}= .06694$$

.20063

Average, .06688

1 : 32 : : x : .06688. x=.00209; per ton=.00209×2000 = 4.18 lbs. = resistance per ton.

Experiment 12.—Same time, place, train and conditions, except run, which was north, as in 10.

Time passing base (300 feet)	27 sec.
Speed per second	11.11 ft.
Speed per minute	666.66 ft.
Speed per hour	7.57 m.
Run	1,079 ft.
Time	182.4 sec.
Time (estimated)	194.2 "

V=11.11 S=1,079 T=182.4

$$F=\frac{V^2}{2S}=.0572$$

$$F=\frac{2S}{T^2}=.0648$$

$$F=\frac{V}{T}=.0609$$

.1829

Average, .061

1 : 32 : : x : .061. x=.001906; per ton =.001906×2000=3.81 lbs. = resistance per ton.

Mem.—Had estimated time been used we would have 3.58.

Experiment 13.—Same place, time and train. Run south.

Time passing base	26.8 sec.
Speed per second	11.19 ft.
Speed per minute	671.4 "
Speed per hour	7.63 m.
Run	925 ft.
Time	166.4 sec.
" (estimated)	165.3 "

V=11.19 S=925 T=166.4.

$$F=\frac{V^2}{2S}=06768$$

$$F=\frac{2S}{T^2}=.06681$$

$$F=\frac{V}{T}=.06725$$

.20174

Average, .06725

1 : 32 : : x : .06725. x=0021016; for one ton, .0021016×2000=4.20 lbs.

Experiment 14.—On low grade. Same train as in 13. Running north. Base line 200 feet. From south end of base line grade is .377 per 100 feet on an average=19.905 feet per mile. Back of south end of base line is level.

Time passing base (200 feet)	11.3 sec.
Speed per second	17.86 ft.
Speed per minute	1,071.4 ft.
Speed per hour	12.17 m.
Run	847 ft
Time	104 sec.
" (estimated)	94.3 sec.

Wind on right side light, and a little in front.

To get at the average resistance on the basis of a uniform retardation as in the first experiments, we have:

$$V=17.86 \qquad S=847 \qquad T=104$$

$$F=\frac{V^2}{2S}=.1883$$

$$F=\frac{2S}{T^2}=.1566$$

$$F=\frac{V}{T}=.1717$$

.5166

Average, .1722

1 : 32 : : x : .1722; x=.005381; per ton, .005381×2000=10.76 lbs.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine	36.6	847	
Tender	23.4	847	
Cars 30	23.8	847	
" 29	24.7	847	156,779.7
" 28	25.5	847	
" 27	25.6	847	
" 26	24.5	847	
" 25	24.2	835	20,207.0
" 24	24.0	803	19,272.0
" 23	24.6	781	19,212.6
" 22	22.0	749	16,478.0
" 21	24.0	717	17,208.0
" 20	23.5	685	16,097.5
" 19	23.9	653	15,606.7
" 18	23 9	621	14,841.9
" 17	24.1	589	14,194.9
" 16	21.8	557	12,142.6
	420.1		322,040.9

322,049.9×7.54 (due gravity)	2,428,188.386
Now take the estimated resistance per ton above, and the weight 420.1×10 76×847 (distance)	3,828,673.772
Other than gravity	1,400,485.386
Divide by 847 (distance),	1,653.406
Divide again by 20 1 (tons), we have	3.935 lbs.

equals resistance other than gravity.

Experiment 15.—Same time, place and train. Light wind in front and right side.

Time passing base (200)	8.2 sec.
Speed per second	24.39 ft.
Speed per minute	1,463.4 "
Speed per hour	16.63 m.
Run	1,983 ft.
Time	148.5 sec.
" (estimated)	121 "

As before,

$$V=24.39 \qquad S=1,982 \qquad T=148.5$$

$$F=\frac{V^2}{2S}=.15008$$

$$F=\frac{2S}{T^2}=.17976$$

$$F=\frac{V}{T}=.16424$$

.49408

Average, .16469

1 : 32 : : x : .16469. x=.0051465; per ton=.0051465×2000=10.293 lbs., equals total resistance per ton, *if* resistance were constant. The grade for 1,000 ft. from north end of base line was, as before, .377 per 100 ft., and beyond that was level, as in 14.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine	36.6	1,000	36,600.0
Tender	23.4	1,020	23,868.0
30	23.8	1,052	25,037.6
29	24.7	1,084	26,774.8
28	25.5	1,116	28,458.0
27	25.6	1,148	29,388.8
26	24.5	1,180	26,460.0
25	24.2	1,200	
24	24.0	1,200	
23	24.6	1,200	
22	22.0	1,200	
21	24.0	1,200	
20	23 5	1,200	283,200.0
19	23.9	1,200	
18	23.9	1,200	
17	24.1	1,200	
16	21.8	1,200	
	420.1		479,787.2

479,787.2 × 7.54 (due gravity).... 3,617,595.488
As before,
420.1 (tons) × 10.293 (estimated resistance) × 1,982 .... 8,570,343.993

4,952,749 505
Divide by 1,982 (distance)....... 2,498,864
Divide by 420.1 (tons)........... 5,948 lbs.
resistance per ton other than gravity.

Experiment 16.—Same time, train and conditions as last. Light wind in front and right side.

Time passing base (200).........	11.4 sec.
Speed per second	17.54 ft.
Speed per minute...............	1,052.6 "
Speed per hour..................	11.96 m.
Run	870 ft.
Time	103 sec.
" (estimated)................	99 "

As before,

V=17.54 S=870 T=103

$$F=\frac{V^2}{2S}=.17681$$

$$F=\frac{2S}{T^2}=.16401$$

$$F=\frac{V}{T}=.17029$$

.51111

Average, .17037

1 : 32 : : x : .17037. x=.005324; .005324 × 2000=10.648=estimated resistance if regularly applied.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine.......	36.6	870	
Tender........	23.4	870	
30............	23.8	870	
29............	24.7	870	160,167.0
28............	25.5	870	
27............	25.6	870	
26............	24.5	870	
25............	24.2	838	20,279.6
24............	24.0	806	19,344.0
23............	24.6	774	19,040.4
22............	22.0	742	16,324.0
21............	24.0	710	17,040.0
20	23.5	678	15,933.0
19..........	23.9	646	15,439.4
18............	23.9	614	14,674.6
17............	24.1	582	14,026.2
16............	21.8	550	11,990.0
	420.1		324,258 2

324,258.2 × 7.54, (due gravity)... 2,444,906.828
As before,
420.1 (wt.) × 10.648 (est. resist.) × 870 (dist.)........... .... 3,891,705.576

Leaving a resistance other than gravity...................... 1,446,798.748
Divide by 870 (distance)........ 1,662.987
Divide by 420.1 (tons).......... 3.878 lbs.

equals resistance per ton other than due gravity.

Experiment 17.—Same train, time and conditions:

Time passing base.............	12.8 sec.
Speed per second...............	15.62 ft.
Speed per minute..............	937.5 "
Speed per hour.................	10 05 m.
Run..........	670 ft.
Time..........................	93 sec.
" (estimated)................	86 "

V=15.62 S=670 T=93.

$$F=\frac{V^2}{2S}=.18207$$

$$F=\frac{2S}{T^2}=.15496$$

$$F=\frac{V}{T}=.16796$$

.50499

Average, .16833

1 : 32 : : x : .16833. x=.00526; .00526 × 2000 = 10.52 lbs.=estimated constant resistance.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine.....	36.6	670	
Tender.......	23.4	670	
30............	23.8	670	
29............	24.7	670	123,950.0
28............	25.5	670	
27............	25.6	670	
26............	24.5	670	
25............	24.2	638	15,439.6
24............	24.0	606	14,544.0
23............	24.6	574	14,120.4
22............	22.0	542	11,924.0
21............	24.0	510	12,240.0
20............	23.5	478	11,233.0
19............	23 9	446	10,659.4
18	23.9	414	9,894.6
17............	24.1	382	9,206.2
16............	21.8	350	7,630.0
	420.1		240 841.2

240,841.2 × 7.54 (due gravity)....	1,815,942.648
As before, 420.1 (tons) × 10.52 (est. resist.) × 670 dist.)	2,961,032.840
Resistanee other than gravity....	1,145,190 192
Divide by 670 (distance).	1,709.239
Divide by 420.1 (tons)	4,068 lbs.

resistance other than due 6ravity.

Experiment 18.—Same train, place and conditions. Wind as in last, about three miles or, perhaps, more per hour on right hand and well ahead.

Time passing base (200)........	25.6 sec.
Speed per second......	7.81 ft.
Speed per minute..............	468.7 "
Speed per hour................	5.32 m.
Run..........................	191 ft.
Time..........................	53 sec.
" (estimated)................	49 "

V=7.81 S=191 T=53

$$F=\frac{V^2}{2S}=.1592$$

$$F=\frac{2S}{T^2}=.1360$$

$$F = V=.1474$$

$$.4426$$

Average, .1475

1 : 32 : : x : .1475. x=.0046; .0046 × 2000=9.22 lbs.=estimated constant resistance.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine.......	36.6	191	
Tender.......	23.4	191	
30............	23.8	191	
29............	24 7	191	35,163.1
28............	25.5	191	
27............	25.6	191	
26............	24.5	191	
25............	24.2	159	3,847.8
24............	24.0	127	3,048.0
23............	24.6	95	2,337.0
22............	22.0	63	1,386.0
21............	24.0	31	744.0
20............	23.5		
19............	23.9		
18............	23.9		
17............	24.1		
16............	21.8		
	420.1		46,525.9

46,525.9 × 7.54 (due gravity)......	350,805.286
420.1 × 9.22 (est. resist.) × 191 distance.........................	739,804.502
Resistance other than gravity.....	488,999.216
Divide by 191 (distance)..........	2,560.206
Divide by 420.1 (tons)...........	6.094 lbs.

resistance per ton other than gravity.

Experiment 19.—Same train, etc.

Wind a little stronger each time; three miles an hour at least.

Time passing base.	26.6 sec.
Speed per second..............	7.51 ft.
Speed per minute..............	450.14 "
Speed per hour................	5.11 m.
Run..........................	179 ft.
Time..........................	51 sec.
" (estimated)................	49 "

V=7.51 S=179 T=51.

$$F=\frac{V^2}{2S}=.15754$$

$$F=\frac{2S}{T^2}=.13755$$

$$F=\frac{V}{T}=.14675$$

$$.44134$$

Average, .14711

1 : 32 : : x : .14711. x=.004597; .004597 × 2000=9.094 lbs.= estimated resistance if constant.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine......	36.6	179	
Tender.......	23.4	179	
30............	23.8	179	
29............	24.7	179	32,953.9
28............	25.5	179	
27............	25.6	179	
26............	24.5	179	
25............	24.2	147	3,557 4
24............	24.0	115	2,760.0
23............	24.6	83	2,041.8
22............	22.0	51	1,122.0
21............	24.0	19	456 0
20............	23.5		
19............	23.9		
18............	23.9		
17............	24.1		
16............	21.8		
	420.1		42,891 1

42,891.1 × 7.54 (due gravity)	323,398,894
420.1 × 9.094 (est. resistance) × 179 (dist.)	683,849.703
	360,450.809
Divide by 179 (dist.).	2,013.687
Divide by 420.1 (tons)...........	4.793 lbs.

resistance other than due gravity per ton.

Experiment 20.—Same time, train, etc.

Time passing base.............	20.8 sec.
Speed per second..............	9.61 ft.
Speed per minute..............	577 "
Speed per hour................	6.56 m.
Run..........................	305 ft.
Time.........................	62 sec.
" (estimated)	63 "

V=9.61 S=305 T=62

$$F=\frac{V^2}{2S}=.151397$$

$$F=\frac{2S}{T^2}=.158688$$

$$F=\frac{V}{T}=.155000$$

.465085

Average, .155028

1 : 32 : : x : .155028. x=9.689 lbs.= estimated constant retarding power per ton.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine.......	36.6	305	
Tender.......	23.4	305	
30	23.8	305	
29............	24.7	305	56,150.5
28............	25.5	305	
27	25.6	305	
26	24.5	305	
25............	24.2	273	6,606.0
24............	24.0	241	5,784.0
23..........	24.6	219	5,387.4
22............	22.0	187	4,114.0
21............	24.0	155	3,720.0
20............	23.5	123	2,890.5
19............	23.9	91	2,174.9
18............	23.9	59	1,410.1
17............	24.1	27	650.7
16............	21.8	....	....
	420.1		88,888.7

88,888.7 × 7.54 (due gravity)......	670,220.798
420.1 × 9.689 (estimated resistance) × 305 (distance).............	1,241,456.414
Total resistance due other than gravity.....................	571,235.616
Divide by 305 (distance)	1,872.903
Divide by 420.1 (tons).........	4 458 lbs.

equals resistance per ton other than gravity.

Experiment 21.—Same train, time and conditions.

Time passing base.............	17.6 sec.
Speed per second..............	11.37 ft.
Speed per minute..............	662 "
Speed per hour................	7.73 m.
Run..........................	405 ft.
Time.........................	70 sec.
" (estimated)...............	71 "

V=11.37 S=405 T=70.

$$F=\frac{V^2}{2S}=.1596$$

$$F=\frac{2S}{T^2}=.1653$$

$$F=\frac{V}{T}=.1624$$

.4873

Average .16243

1 : 32 : : x : .16243. x=.005107; .005107 × 2000=10.214 lbs.= estimated constant resistance per ton.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine.......	36.6	405	
Tender.......	23.4	405	
30.	23.8	405	
29............	24.7	405	74,560.5
28	25.5	405	
27............	25.6	405	
26............	24.5	405	
25	24.2	373	9,026.6
24............	24.0	341	8,184.0
23............	24.6	309	7,601.4
22............	22.0	277	6,094.0
21............	24.0	245	5,880.0
20............	23.5	213	5,005.5
19............	23.9	181	4,325.9
18............	23.9	149	3,561.1
17............	24.1	117	2,819.7
16............	21.8	85	1,853.0
	420.1		128,911.7

128,911.7×7.54 (due gravity)....	971,994.218
420 1×10.214 (est. resistance) × 405 (dist)......................	1,737,815.067
Resistance other than gravity....	765,820.849
Divide by 405 (distance).........	1,644.002
Divide by 420.1 (tons)...........	3.913 lbs.

resistance per ton other than gravity.

Experiment 22.—Same train and conditions.

Time passing base......	16.4 sec.
Speed per second..............	12.2 ft.
Speed per minute....	732 "
Speed per hour.......	8.3 m.
Run	415 ft.
Time.........................	70.5 sec.
" (estimated)...............	68 "

V=12.2 S=415 T=70.5

$$F=\frac{V^2}{2S}=.17932$$

$$F=\frac{2S}{T^2}=.16703$$

$$F=\frac{V}{T}=.17305$$

.51937

Average, .17312

1 : 32 : : x : .17312. x = .00541; .00541 × 2000 = 10.83 lbs. = estimated constant resistance per ton.

Train.	Tons.	Distance on grade.	Tons × distance.
Engine.......	36.6	415	
Tender... ..	23.4	415	
30............	23.8	415	
29............	24.7	415	76,401.5
28...........	25.5	415	
27............	26.6	415	
26............	24.5	415	
25............	24.2	383	9,268.6
24............	24 0	351	8,424.0
23............	24.6	319	7,847.4
22.	22 0	287	6,314.0
21............	24.0	255	6,120.0
20............	23.5	223	5,240.5
19	23.9	191	4,564 9
18	23.9	159	3,800.1
17.	24.1	127	3,060.7
16	21.8	95	2,071.0
	420 1		133,112.7

133,112.7×7.54 (due gravity)....	1,003,669.758
420.1×10.82 (est. resist.) × 415 (dist.).........	1,883,375.030
Resistance other than gravity....	883,705.272
Divide by 415 (distance)........	2,129.410
Divide by 420.1 (tons)..........	5,068 lbs.

resistance per ton other than due gravity.

See Summary of Experiments next page.

A portion of the resistance other than gravity in these experiments was atmospheric resistance, partly due to speed of trains and partly due to wind.

In experiments 1 to 6 and 8 to 9 the wind was so light and so near right angles that its effect could hardly be estimated.

In 10 and 12 it was on the rear quarter, 30 or 40 degrees from the line of the train and about four miles per hour.

In the other experiments, when it is mentioned it was on the right hand, 30 to 40 degrees from dead ahead, and estimated about four miles per hour.

In order to make our estimates we will assume that the pressure per square foot due speed is as laid down by various authorities and as given below:

Speed per hour.		Velocity per second.	Pressure per square foot.
1	....	....	....
2	....	....	....
3	....	4.4	.044
4	....	5.87	.079
5	....	7.83	.123
6	....	8.8	.177
7	....	10.25	.241
8	....	11.75	.315
9	....	13.2	.400
10	....	14.67	.492
12	....	20.5	.964
15	. ...	22.	1.107
16	....	23.45	1.25
18	....	26.4	1.55

The train consisted of an engine and fifteen coal cars, loaded as high as coal could well be piled on.

The surface presented by the engine we estimated to be about 64 square feet, and as the wind was at an angle, it took effect on the sides of the train as well as upon the ends of the cars which presented a surface, and the coal, and we estimated that the surface so acted on was about six square feet per car. This would make the whole surface 154 square

SUMMARY OF EXPERIMENTS.

No.	Speed per hour.	Started on Grade.	Started on Curve.	Run on Grade.	Run on Curve.	Distance.	Time.	Est. time.	Resist. due gravity.	Other resist.
1	11.70	level.	....	52.8	....	538 ft.	..	63 sec.	20 lbs.	5 98
2	9.43	"	....	"	....	403 "	..	58.3 "	"	6.45
3	6.81	"	....	"	....	234 "	..	47 "	"	8.09
4	7.70	"	....	"	....	316 "	..	56 "	"	5.95
5	10.65	"	....	"	....	495 "	..	63 "	"	5 38
Av'ge.	9.25	....	....	....	....	397 ft.	..	57.4 sec.	20 lbs.	6.37
6	11.33	52.8	....	52.8	2°	321 "	..	39 "	20 "	6.55

No.	Speed per hour.	Started on Grade.	Started on Curve.	Run on Grade.	Run on Curve.	Time. Actual	Time. Est'd.	Distance run.	Resistance. Gra'y.	Resistance. Other.	
8	12.08	Level	..	Level	..	..	116.5	1,500	..	5.19	r'nning at speed 5.52 end of 1,500 feet.
9	7.82	"	..	"	..	..	221	1,272	..	3.246	
10	6 73	"	..	"	..	185.5	205	1,013	..	3.346	
11	6.04	"	..	"	..	132.5	133.5	582	..	4.18	going south
12	7.57	"	..	"	..	182.4	194.2	1,079	..	3.81	
13	7.63	"	..	"	..	166.4	165.3	925	..	4.20	" "
Av'ge.	7.98	..	..	..	..	..	..	..	..	3.995	....
"	7.16	..	..	..	..	..	..	976	..	3.756	9 to 13
14	12.17	..	..	19.9	..	104	94.3	847	7 54	3.935	
15	16.63	..	..	"	..	148.5	121	1,982	"	5.948	
16	11.96	..	..	"	..	103	99	870	"	3 878	
17	10.65	..		"	..	93	86	670	"	4.068	
18	5.32	3-5 l'l	..	"	..	53	49	191	"	6.094	
19	5 11	2-5 up	..	"	..	51	49	179	"	4.793	
20	6.56	grade	..	"	..	62	63	305	"	4.458	
21	7.73	19.9	..	"	..	70	71	405	"	3.913	
22	8.30	..	..	"	..	70.5	68	415	"	5.068	
	9.38	..	..	..	..	83.8	..	651.6	7.54	4 684	Average.

8 to 22.................... 4.408 Total.

Average all on straight line 1-5, 8-22................................ 4.898

No 6 on two degrees curve.................................... 6.55

feet, and upon this surface we have figured, although Mr. Chanute estimates that the additional surface for each car is about twenty per cent. of the first surface presented, or a little more than twice what we have taken. If he is right, results 67 per cent. greater than we show would be reached.

As we do not wish to *over*-estimate, we will assume our figures for 154 square feet for wind pressure.

The wind pressure varies as the square of the velocity; as our train moved from a given speed to a standstill we must average the effect, which would be as the average of the square of the various speeds during the time—which within the limits of our experiments would be substantially one-fourth less than half the maximum effect, or three eighths of the maximum effect, *i. e.*, maximum pressure. The variation from this is so small that it will make no practical difference in figures.

On this basis we figure as follows:

EXPERIMENT 1.

Pressure of wind	.0	
" due maximum speed.	.964	lbs.
Three-eighths of this	.362	"
154 sq. ft. × .362 lbs. pressure	55.748	"
Divide by 420.1 tons (wt. of train). resistance per ton due atmospheric causes.	.132	"

[In the same way the writer gets the atmospheric resistance for each of the 24 experiments. It is not thought essential to print the calculations here.]

From these figures we may conclude that the frictional resistance of *that train*, including the engine, was 4.725 lbs. per ton, though many of the results are below this.

You will note that in five cases the estimated time taken in the stop was more than the actual, and in eight cases it was less.

You will note that the initial speed in cases where the estimated time exceeds the actual is low, averaging 6.72 miles; while in cases where the estimated time is less than the actual, the initial speed is higher, averaging 9.72 miles, or almost 45 per cent. higher.

Now, in the first ten cases the average initial speed is on an average of 9.69 miles, and, if the same rules hold, we will have an estimated time of considerably *less* than the actual.

In the case of No. 12 we found that an increase of six per cent. of the estimated time over the actual would, in calculation, show a six-per-cent. decrease in the resistance.

If the time used in the calculation of cases 1 to 9 is too small, then the use of the actual or correct time in the calculation would show a resistance less

RESULTS TABULATED.

Series.	Experiments.	Resistance other than gravity.	Atmospheric resistance.	Friction and other resistance.
1	1	5.98	.182	5.848
	2	6.45	.062	6.388
	3	8.09	.091	8.009
	4	5.95	.030	5.920
	5	5.38	.090	5.290
Average				6.291
2	6	6.55	.110	6.440 on 2° curve.
3	8	5.190	.204	4.986
	9	3.246	.044	3.202
	10	3.346	.002	3.344
	11	4.180	.056	4.124
	12	3.810	.026	3.784
	13	4.200	.069	4.131
Average				3.929
4	14	3.935	.163	3.772
	15	3.948	.215	3.733
	16	3.878	.162	3.716
	17	4.068	.130	3 938
	18	6.094	.049	6 045
	19	4.793	.047	4.746
	20	4.458	.059	4.399
	21	3.913	.070	3.843
	22	5.068	.079	4.989
Average				4.353
Average 8 to 22				4.183
1 to 5 and 8 to 22				4.710

Table Showing Actual Time, Estimated Time, Initial Velocity in Miles per Hour, and Frictional Resistances as Calculated.

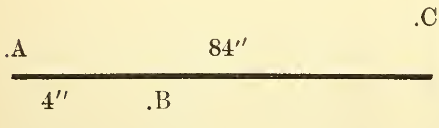
Series.	Experiments.	Observed time.	Estimated time.	Initial speed.	Frictional resistance.
	1	....	63	11.70	5.848
	2	....	58.3	9.43	6.388
1.	3	....	47.	6.81	8.309
	4	....	56.	7.70	5.920
	5	....	63.	10.65	5.290
2.	6	....	39.	11.33	6.440 on 2° curve.
	8	....	116.5	12.08	4.986
	9	....	221.	7.82	3 202
3.	10	185.5	205.	6.73	3.344
	11	132.5	133.5	6.04	4.124
	12	182.4	194.2	7.52	3.784
	13	166.4	165.3	7.63	4.131
	14	104	94.3	12.17	3 772
	15	148.5	121.	16.63	3.733
	16	103	99	11.96	3 716
	17	93	86	10.65	3.938
4.	18	53	49	5.32	6.045
	19	51	49	5.11	4.746
	20	62	63	6.56	4.399
	21	70	71	7.73	3.843
	22	70.5	68	8.30	4.989
Average.	....	....	....	9.041	

than that tabulated by a percentage equal to the error in the time element.

How much of the resistances calculated is due to imperfect track is unknown. In no case was the track perfect, though it was fair, and an average sand-ballasted track.

Some very crude experiments were made to test the frictional resistance both at the start and when in motion, the cars used being of the lot used in former experiments, weight of which we had.

Our arrangement for measuring the resistance being a lever with length four inches and eighty-four inches, with spring balance to measure strain; thus:



This lever being upon one empty coal car at one end, the point A being fixed upon the car, the point B being upon a wire which was fastened to the draw-bar of the car to be tested; the point C being the point to which the spring balance was fixed, the other end of the balance being put to the lever.

We found that the arrangement was not accurate, as, for instance, the weight of the parts would show on the balance, and we had to start in by an allowance to provide against such influence. The pointer would bob about rapidly, so that an exact reading could hardly be taken. We attempted to read the amount that it took to start the car, and then how much to keep it going. We could not get an exactly steady motion, and the strains after the start were spasmodic in spite of all we could do.

The point selected was upon a level piece of track, on straight line, steel rail and good surface.

The first test was with car 2,057, weight 47,700 lbs.

We give, first, the number of the test; second, the amount our scale registered (after deducting our allowance) to start the car; third, the range through which our pointer vibrated (after deducting as before) to keep the car going:

No. Test.		Pointers, when car started.	Range of pointers to keep moving.
1	....	29	4–12
2	....	24	2–10
3	....	24	4– 8
4	....	30	4– 8
5	....	14	4– 8
6	....	30	4–10
7	....	12	3– 6
8	....	14	3–10
9	....	13	4– 8
10	....	16	4–10
11	....	11	....
12	....	8	2– 6
13	....	8	2– 5
14	....	12	2– 6
15	....	11	....
16	....	13	....
17	....	16	....
18	....	10	....
19	....	15	....
20	....	21	....
21	....	15	....
22	....	20	....
23	....	10	....

Footing of experiment to start 355
Average.............................. 15.44
Multiply by the leverage, 21, and we have 324.24
Divide by 25.85 (tons)............... 13.595

which we may take as the resistance per ton upon this car at the start.

Foot the average of amounts required to keep the car in motion, and we have 745
Which gives an average of........... 5.73
Multiply by 21 (leverage).............. 120.33
Divide by 23.85 (tons)................ 5.04
equals resistance per ton.

The wind was light and upon side, so did not affect it.

Another car was taken, weight, 47,100 lbs.=23 55 tons.

The result as a whole was very unsatisfactory, and of little or no value, except to show that the frictional resistance from a start is much more than while in motion.

The average resistance to a start was 17.27 lbs. per ton, while that to keep in motion seems to have been about 5.10 lbs. per ton, or less than one-third of the former.

As before,

Test.		Start.	Range
24	....	21	....
25	....	21	....
26	....	24	....
27	....	21	....
28	....	27	4– 8
29	....	12	8–12
30	....	8	4– 8
31	....	19	3– 8
32	....	17	7–14
33	....	15	2–10
34	....	14	6–14
35	....	19	....
36	....	26	....
37	....	28	....
38	....	30	....
39	....	28	2–12
40	....	27	....
41	....	28	....
42	....	19	8–12
43	....	31	4–10
44	....	27	....
		462	78
Av'ge.	....	22	7.8

22×21=462, divided by 23.55=19.62 =average resistance per ton to starting.

7.8×21=163.8, divided by 23.55=6.96 =resistance when running very slowly.

Next car: weight, 50,700.

Test.		Start.	Range.
45	....	31	....
46	....	28	4–10
47	....	26	2– 6
48	....	34	4–12
49	....	30	3– 6
50	....	31	3– 8
		180	30
Av'ge	....	30	6

30×21 (leverage)=630, divided by 25.35=24.85 average resistance at start.

6×21=126, divided by 25.35=4.97= resistance in motion.

The motion in last car was about three or three and a half miles per hour, while in other two it was very much less; just barely a motion.

THE PERMISSIBLE STRAIN UPON BRICKWORK.

By Dr. BÖHME.

Mittheilungen aus der "Prüfungsstation für Baumaterialien."

Translated for Abstracts of the Institution of Civil Engineers.

The experiments given in detail in this paper were made to ascertain the crushing strength of brickwork composed of different kinds of brick with various mortars. The mortars used were made with either lime or Portland cement, in each case mixed with sand. The bricks were those chiefly in use in Berlin. The composition of the mortar was found to have great influence upon the strength. Brickwork set in a mortar composed of 1 part lime and 2 parts sand possessed only 44 per cent. of the strength of the bricks alone, while the mortar composed of 1 part Portland cement and 3 parts sand raised the percentage to 63. A great number of tests were made, full particulars of each being given. The results obtained are summarized in the following table, in which the safety limit is taken as one-tenth of the absolute crushing strength.

Description of Brick.	Average Crushing Strength of Brick Alone.	Permissible Strain upon Brickwork with Mortar composed of—			
		1 Lime. 2 Sand. 4.4 per cent.	7 Lime. 1 Cement. 16 Sand. 4.8 per cent.	1 Cement. 6 Sand. 5.5 per cent.	1 Cement. 3 Sand. 6.3 per cent.
	Lbs. per Square Inch.	Lbs. per Square Inch.			
Ordinary stocks.....	2,930	129	139	161	185
Selected "	3,669	162	176	202	232
Clinkers.............	5,390	237	259	296	341
Porous Bricks.......	2,617	115	125	144	165
Porous perforated do.	1,195	53	57	65	75
Perforated do	2,759	121	132	152	171

The figures arrived at by the author are in each case higher than those upon which the building regulations of Berlin are based.

Russian Mineral Resources.—The Russian people appear to have some cause for being dissatisfied with the way in which the rich resources of their own country are being neglected. At the racent conference of the ironmasters of Poland, at Warsaw, a petition was adopted praying the Government to revise the traffic rates of the principal Polish lines, and alleging that a ton of English rails can be conveyed from England to Warsaw as cheaply as a ton of Polish rails from the Radom and other districts of West Russia. During the conference it was mentioned that the firm of Krampst & Co. had realized a clear profit of £44,350 during the past year, enabling it to declare a dividend of 9 per cent. It was also asserted that, while the neighboring iron mines of Silesia are becoming poorer every year, and do not yield more than 28 per cent. of iron, the yield of the Russian mines of Poland ranges between 30 and 45 per cent., in consequence of which, foreign firms have applied for upwards of 100 plots of ground in the Dombrova district, in order to be able to extract the ore and dispatch it to Silesia. In the Krivoy Rog district, of South Russia, the yield of magnetic ore is stated by a correspondent to be 65 per cent., and a French company is working the deposits.

VENTILATION OF SEWERS.*

By GEORGE EEDES EACHUS, M. I. C. E.

From "The Architect."

In presenting a paper on the ventilation of sewers for the consideration and discussion of the Society, the author has confined himself to giving a short account of what has been done, and a description of a system which he has personally adopted as the result of investigation into the working and defects of previous systems.

Until the last twenty or thirty years it was not the general custom to ventilate sewers, and most of the main sewers themselves were constructed without manholes or ventilators, the branch sewers often discharging into cesspools, the overflow from which was connected with the main sewers—the cesspools being as far as practicable, hermetically sealed and seldom emptied, the consequence being that the stagnant sewage was decomposed, and the germs of disease rapidly spread.

The numerous cases of typhoid and kindred diseases arising from these defects in works of drainage caused sanitary reformers to awake to the dangers of pent-up sewage, and it was then sought to send the sewage away as far and as quickly as possible, and outlets were provided for the escape of the sewer gas both from cesspools and sewers.

The modern French system has been based somewhat on this system, the cesspools themselves being retained, but made as air and watertight as possible, with upcast shafts to take the sewer gas from the cesspools, and the soil-pipe carried down from the top of the house, with an outlet to the air at the top, and the bottom extended below the surface level of the liquid retained in the cesspool as a trap. This system, called the *fosse fixe*, is sometimes connected with a sewer, sometimes not, and of course, especially in the latter case, involves periodical and frequent cleansing, and this necessity has caused the invention of several ingenious arrangements for emptying the *fosse fixe*, or cesspool; but this system is much more costly than the English, owing to the large annual cost both of cleansing the cesspools and carting away the soil, otherwise the effect where the work is scientifically and well executed, and the emptying and cleansing constantly attended to, is to keep the sewer gas from being discharged within the dwelling. But much more sewer gas is generated than in the English system of constant flow, and the annual cost is about five times the cost of removal by water, or about 12s. 6d., as compared with 2s. 6d. per head per annum in the case of large towns.

The main sewers in France, and generally abroad, are, as a rule, very badly ventilated, and their construction is often such as to favor the generation of large quantities of sewer gas, discharged often by gullies and other openings immediately under the nose of foot passengers.

In England the sewers, as far as their liability to generate sewer gas is concerned, have been generally much better constructed than abroad, and of much smaller dimensions than the French, and better proportioned to the normal flow of sewage, filling, consequently, at all times, a larger portion of the sewer, and the sewage runs with a greater and, for the sewers, more self-cleansing velocity. Sewers so constructed also expose a smaller proportionate surface of sewer wall to the alternate wetting by sewage and drying and decomposition which takes place, especially at certain seasons of the year, and when dry weather follows after a storm. The English sewers are better constructed to avoid generation of sewer gas, and better cleased, but, until recently, very little has been done in the way of ventilating the sewers except by the insertion of a greater or less number of stink outlets, and next to nothing has been done to render sewer gas escaping at these blowholes innocu-

* A paper read at a meeting of the Civil and Mechanical Engineers' Society.

ous, nor until recently has much been done to assist in the cleansing of sewers in a practical manner. It is needless to inform engineers that it is absolutely necessary to keep sewers clean, either by natural or artificial flushing, and for this purpose, where a sewer is laid with a flat gradient, much more is needed than an occasional flush at a few points from a 500 or 1,000 gallons self-acting flush-tank, the flush from which, in a sewer of moderate size, is spent in a very short distance. Most sewerage engineers who have turned their attention to the ventilation of sewers have contented themselves with making the stink outlets, or ventilating manholes, at intervals of from about 60 yards and upwards, the distance generally adopted being over 100 yards, the idea being that the sewer gas discharging at these outlets would be sufficiently diluted with atmospheric air to render it innocuous. The author's own practice has been, of late, to place ventilating manholes 200 ft. apart as a convenient distance for examination, and quite far enough for the free circulation of air, which the author seeks to secure in every sewer.

As the age of sewers has increased, all the defects due to defective private-house drainage and connections of house drains with the sewers have become apparent, and the smells from some ventilating manholes have so increased, that public opinion has been roused even to the extent of compelling the stoppage of ventilators, instead of adding to their number; the public generally, in a time of excitement and fear of microbes and bacilli, acting upon the principle that what the eye does not see or the nose smell, the heart does not grieve at.

When ventilators were first introduced, many attempts were made to filter the sewer gas before allowing it to discharge into the open air, and many and complicated were the ventilators patented, charcoal being generally the substance employed to filter the gas; but owing partly to the charcoal being often so displaced, when the filter was put in, that the sewer gas could pass freely through the open spaces, partly owing to the ventilators being so constructed that the charcoal was constantly wet and clogged, so as not to act properly, owing to these and other causes, these charcoal trays and filters have gradually come into disuse.

Various attempts have also been made to create strong upcast draft by furnace chimneys, cowls, or other artifical means, but these attempts have never been more than locally, and then only very partially successful.

The author having himself encountered most of these practical difficulties, tried a number of experiments at his own house and on sewers under his charge, in order to test by the practical and elementary sense of smell (which is the test put by the public, rather than by delicate anemometers and other means, when and under what conditions the sewer gas was most freely generated and discharged. The next point was to ascertain how the flow of sewer gas could be so regulated as to prevent undue accumulation at any one point, and how the passers by the ventilators could be relieved of the constantly unpleasant smell experienced at many places. The result of these experiments was to show that a well-constructed sewer, with a moderately quick fall and constant flow, running from one-third to one-half full, or more, of sewage, generated the least quantity of sewer gas; also that a sewer similarly constructed, with a similar fall, seemed to form the best channel for the conveyance of sewer gas; and for this reason, where practicable, the author of this paper prefers to have a sloping outlet, up which the sewer gas may ascend, so as to arrive at its point of discharge with the least possible obstruction. More sewer gas was found to be generated in the larger and badly-constructed sewers, especially in those with flat fall and varying flow, and where the velocity of flow is insufficient for the sewer to be self-cleansed. The sense of smell is, of course, most apparent when the necessary conditions of stagnation and comparative temperatures of the sewer and of the air happen to meet, and hot fluids entering the sewers always add to the aroma and increase the difficulty of dealing with the gas.

The flow of the gas and the sense of smell both seem to travel, as a rule, in the direction inverse to the flow of sewage, but this rule is by no means without exceptions. For the purposes of this paper it is, however, better to deal with the general rule, which is, that sewer gas, when generated, travels upward, and tends to accumulate in the upper districts at points where there is some check to the flow, or some local circumstance to make a ventilating manhole a good upcast shaft. The author had a good case in point where a clean, new, well-laid sewer, with a rather quick fall and no sewage in it, served as an admirable ventilating shaft for an old sewer.

To prevent this accumulation of sewer gas—to dilute the gas with atmospheric air, and to filter the diluted gas before its discharge—the author, in conjunction with Mr. Maignen (the well-known patentee of the *Filtre rapide*), has taken out a patent for localizing the sewer gas, diluting it as much as possible, and filtering it through a charcoal filter in such a way as to overcome the disadvantages above referred to. The accumulation is prevented by localization, and this is effected by means of double or divided manholes provided with stops or valves, placed at the lower part of the middle division in each manhole. The model and drawing show the general arrangement by which the air is allowed to enter the sewer through that part of the manhole called the air inlet. The air passes up the line of sewer, mixing with the sewer gas as it travels, until it comes to the valve or stop at the next manhole, which prevents its further progress, and turns it through the filter out at the ventilating cover or gas outlet. This valve or stop is made in sections, being like a balance valve on a common spindle, and each of the lower sections working independently of those above, so that, while the sewage flows down the sewer, the flow of gas in the opposite direction is arrested and diverted up the gas outlet at each manhole.

In trying to ascertain the velocity and force with which sewer gas travels, the author has not yet met with great success; but he finds that, except with large differences of temperature or sudden variation in flow, the current is hardly perceptible, and yet without any perceptible current of gas there may be very strong smells perceptible at many ventilators. These would appear to be due to the diffusion of the gases which always takes place, rather than to an actual current; and this will be readily understood by reminding the members of the experiment which shows that if a heavy gas is placed in the lower half of a closed vessel, and a light gas in the upper part, the two parts divided by plaster of Paris, the gases are found to diffuse, even passing through a considerable thickness of plaster of Paris to mix one with the other.

In carrying out this system, the author prefers, where practicable, instead of having the outlet of the upcast shaft at the surface of the road, to conduct a pipe by easy lines up the side of a house or other convenient place. Where this can be done it is not essential in many instances to filter the sewer gas, but where it cannot be done the author has found, after nearly twelve months' experience, that the filter of the form shown by the model effectively does away with any objectionable smell from the sewer gas, the charcoal cannot be displaced to allow the free passage of the gas, and both the form of the filter and the overflow for the water provided in the dirt box prevent the charcoal becoming wet or damp, even after many months' use. The vapor arising from the sewage is condensed on the underside of the filter without wetting the charcoal.

A very similar arrangement to that above described has been used by the author in the drainage of the Town Hall, Edmonton, and there is no difficulty in the general application of the system for house drainage as well as sewerage.

The author is an advocate for trapless valve closets and drains without siphons, and for the straightest possible lines of soil pipes and ventilating pipes, so as to maintain a free circulation from each air inlet to the adjoining gas outlet, and the air ought, in the author's opinion, to have a free circulation through every foot of sewer drain and soil pipe. The variation between the day and night flow in this system secures fresh supplies of atmospheric air in each length of each sewer every night. The system can in most cases be easily adapted to existing arrangements of sewerage and house drainage.

It has now been in work adjoining the Town Hall, Edmonton, for twelve months, and for nearly nine months in another street at Edmonton; and Mr. Laws, the engineer, of Newcastle, who saw the model at the Exhibition this year, where it was awarded a medal, has been twice to Edmonton to inspect its working, and intends trying it in certain places in Newcastle which have hitherto given trouble.

The author finds that the bottom sections of the valve are not required, and, indeed, the system seems to work best without them. It is not even necessary to stop the back flow of sewer gas that the valve should reach the sewage at its normal level, although the author prefers that it should nearly, if not quite, touch it.

No stoppage or heading up of either of the sewers where it has been used has taken place, although one of them has only a fall of 4 feet in a mile.

In concluding this paper, the author would again call attention to the fact that under this system no lodgment or deposit can take place between the closets in the house and the final outlets, the circulation of both air and water being quite free throughout; and the whole system of sewers is so divided into sections that there can be no accumulation of sewer gas at any one point, and any gas generated is well diluted with air, and well filtered before it escapes into the atmosphere.

The temperature in the sewers is lower than under any other system. Any kind of filter or disinfectant can be used in connection with the system above described, and it has been found satisfactory as regards the prevention of smells both from the street manholes and house drains. The manholes are usually constructed in concrete.

PRIME MERIDIAN TIME.*

From "Nature."

On the first day of the month, the President of the United States, in his message at the opening of Congress, referred to the International Meridian Conference, lately convened in Washington, in the following words: "The Conference concluded its labors on November 1, having, with substantial unanimity, agreed upon the meridian of Greenwich as the starting point whence longitude is to be computed through 180° eastward and westward, and upon the adoption for all purposes for which it may be found convenient of a Universal Day, which shall begin at midnight on the initial meridian, and whose hours shall be counted from zero up to twenty-four."

The Canadian Institute is peculiarly interested in this announcement. No society, literary or scientific, has taken a more important part in the initiation of the movement to reform our time system, of which the success is, to some extent, indicated in the President's words. It therefore appears to me fit and proper that I should recall to your attention the various steps which from time to time have been taken, so that we may possess a record of the events which have led to the now almost general recognition of the necessity for a new notation.

Six years ago, on several occasions, the meetings of the Institute were engaged in discussing the subject of time-reckoning, and the selection of a prime meridian common to all nations. Papers were read and arguments wese advanced, with the view of showing the necessity of establishing a cosmopolitan or universal time, by which the events of history might be more accurately recorded, and which would respond to the more precise demands of science, and generally satisfy the requirements of modern civilization. The "Proceedings" of the Institute for for January and February, 1879, give at considerable length the views submitted and the suggestions offered to meet the new conditions of life. While, on the one hand, it was argued that the introduction of a comprehensive scheme by which time could be universally reckoned was highly desirable, it was equally maintained that the determination of a common prime meridian for the world was the key to its success, and that the estab-

* This paper, giving the early history of a movement which is now attracting such general attention, was reprinted in *Nature* from the "Transactions" of the Canadian Institute.

lishment of such a meridian, as a zero, recognized by all nations, was the first important step demanded.

These "Proceedings" were brought under the notice of His Excellency the Marquis of Lorne, then Governor-General of Canada. In the name of the Institute, they were submitted, in the form of a memorial, with the hope that His Excellency would see fit to lay them before the Imperial Government, that they would by these means obtain the attention of the several scientific bodies throughout Europe, and that some general systematic effort would be made in the right direction to secure the important objects sought to be obtained.

Through the good offices of His Excellency, copies of the Canadian Institute "Proceedings" found their way to the British Admiralty, the Astronomer Royal, Greenwich, the Astronomer Royal for Scotland, Edinburgh, the Royal Society, the Royal Geographical Society, the Royal Astronomical Society, the Royal United Service Institute, and other societies of eminence and weight in the United Kingdom. Copies of the papers were likewise sent through the Imperial Government to the Governments of the the following countries viz.:

France,
Italy,
The United States,
Austria,
Brazil,
Japan,
Spain,
Switzerland,
Greece,
Germany,
Norway and Sweden,
Russia,
Belgium,
Denmark,
The Netherlands,
Portugal,
Turkey,
China.

In the year following, the American Metrological Society issued a report of the Committee on Standard Time. The report bears the name of Mr. Cleveland Abbe, the chairman of the committee, and the date of May, 1879. It draws attention to many of the causes calling for the establishment of accurate time, and the attempts made since the establishment of the electro-magnetic telegraph to make the notation of time synchronous. While pointing out that this result had been obtained in Great Britain through the efforts of Professor Airy, Mr. Cleveland Abbe gave a list of the various observatories on this continent, which are in possession of the necessary apparatus and force proper to furnish astronomically accurate time by telegraph. Writing in February, 1880, while giving the resolution adopted by the Society, recommending the adoption of accurate time by telegraph, from an established astronomical observatory, Mr. Cleveland Abbe points out that the subject of accurate time has been taken up by the Horological Bureau of the Winchester Observatory of Yale College, and that the most perfect apparatus had been received for the purpose of distributing New York time with the highest degree of uniformity and accuracy.

Mr. Cleveland Abbe's own remarks on the subject are of high value. He forcibly points out the difficulties and inconveniences under which railway operations in America labor from the want of a proper system of time. To show this fact in greater force, he gives the 74 standards then followed. These several standards he proposed to set aside and replace by standards each differing one hour, or 15° of longitude.

While recommending this course, the report sets forth that the change would only be regarded as a step towards the absolute uniformity of all time-pieces, and the Society passed resolutions, that absolute uniformity of time is desirable; that the meridian six hours west of Greenwich should be adopted as the National Standard to be used in common on all railways and telegraphs, to be known as "Railroad and Telegraph Time": that after July 4, 1880, such uniform Standard Time should be the legal standard for the whole country, and that the State and National Legislatures should be memorialized on the subject.

Mr. Cleveland Abbe, in this report alluded to the previous "Proceedings" of the Canadian Institute.

The active sympathy of the Marquis of Lorne greatly aided the movement of time reform in its early stages. In 1879, in his official position as Governor-General, he had been the recipient of the papers published by the Canadian Institute, and had transmitted them to Great Britain, and, through the Imperial Government, to the several European centers. In 1880, it was learned that the Report to the American Metrological Society, above alluded to, would shortly be issued. Accordingly, advance copies were obtained from New York, and, together with additional papers issued by this Institute, they were transmitted by His Excellency to the following European Societies, and the special attention of their members was directed to the documents themselves:

1.	The Institut de France...	Paris.
2.	Société de Géographie....	Paris.
3.	Société Belge de Géoraphie	Brussels.
4.	Königliche Preussische Akademie der Wissenschaften....	Berlin.
5.	Gesellschaft fur Erdkunde	Berlin.
6.	Kaiserliche Akademie der Wissenschaften ...	Vienna.
7.	K. K. Geographische Gesellschaft...............	Vienna.
8.	Nicolaievskaia Glavnaia Observatoria	Pultowa.
9.	Imper. Rousskae Geograficheskoe Obschestou....	St. Petersburg.
10.	Imper. Akademia Nauk..	St. Petersburg.
11.	Société de Géographie....	Geneva.

By this means attention was obtained for the subject in Europe, and when I submit evidence of the fact, I think you will agree with me that no little of the success which has attended the movement is owing to our late Governor-General. We must all acknowledge how much we are indebted to him for the great personal interest he has always shown on the subject. We are certainly warranted in forming the opinion that the dissemination of these papers, under such distinguished auspices, awakened attention to the arguments they contain. and prepared the way for the subsequent action taken at the International Geographical Congress at Venice, at the Geodetic Congress at Rome, and, more recently, at the Conference at Washington.

Mr. Wilhelm Förster, Director of the Berlin Observatory, enters into the subject at length in a paper "Zur Beurtheilund Einiger Zeitfragen, insbesondere gegen die Einfuhrung einer deutschen Normalzeit." [A review of some considerations on Time, especially against the introduction of German National Uniform Time.]

Mr. Förster proceeds to say: "The British Government is now transmitting, through its representatives, although, at the same time, it declares itself neutral, a proposition which has been published by a society of scientific men in Canada, which aims at the establishment of a cosmopolitan normal datum (Prime Meridian) and of Universal Time, and also the establishment of 24 meridians of an hour apart, by which local time will be absorbed." The first proposal Mr. Förster describes as an important sign of the times, and evidently favors it.

He strongly protests against the establishment of a National German Time; but for railway business, and for such matters of communication as require precision, also for the form of expression of all scientific relations to time, Mr. Förster points out that a Universal Time common to the whole world is to be recommended.

Dr. G. von Boguslavski, in the *Verhandlungen der Gesellschaft fur Erdkunde* ("Transactions of the Geographical Society of Berlin"), commends the new scheme as it has been put forth in the Canadian Institute papers, and foretells that it will be a matter of fact in a short time.

Col. Aden, Director of the Military School, Belgium, has two papers in the *Bulletin de la Societe Belge de Géographie.* He supports the proposal to establish Universal Time, and expresses the opinion that longitude throughout the world should have a common notation, dating from one universally-adopted Prime Meridian.

Col. Wauverman, President of the Geographical Society of Antwerp, in the *Bulletin* of that Society, 1882, advocates the change, and with ability meets the arguments raised against it, showing them to be groundless and arising from a want of thoroughly understanding the question.

In Spain, the proposals have met with full support. All the papers issued by the Canadian Institute have been translated and published in a paper of 80 pages by the Revista General de Marina. The translator, Don Juan Pastorin, an officer of the Spanish navy, is warm in his commendation of the scheme, and takes a wise and comprehensive view of the whole question. The Spanish Government secured the advantage of this gentleman's services as delegate to the Washington Conference.

M. Otto Struve, the well-known Astronomer and Director of the Imperial Observatory, Pultowa, reports on the papers transmitted by Lord Lorne to the Imperial Academy of Science at St. Petersburg. He gives his adherence to the establishment of Universal Time, based, as suggested, on a Prime Meridian common to the whole globe, and strongly advocates counting the hours in one series up to 24.

In England, the Royal Society considered favorably both the establishment of a Universal Time and the determination of a common Prime Meridian. While the present Astronomer Royal, Mr. Christie, takes a favorable view of the question, his predecessor, Sir G. B. Airy, reported unfavorably. The report of the Astronomer Royal for Scotland, Prof. Piazzi-Smith, is decidedly adverse. These documents have been transmitted to the Institute.

In Italy, the Italian Geographical Society has given its countenance to a work by Mr. Fernando Bosari, who, in a pamphlet of 68 pages, reviews the whole question at length, and lays down three principles: 1. The determination of a Zero-meridian. 2. The establishment of Cosmopolitan Time based upon it. 3. The notation of the hours from 1 to 24 in a continuous series.

The question of a Universal Time and the selection of a Prime Meridian is discussed with ability in a paper published by M. Thury, Professor at the University of Geneva.

At the meeting of the Association for the Reform and Codification of the Laws of Nations, at Cologne, Prussia, in 1881, the question of regulating time on the new system was considered and resolutions moved.

In the same year (1881), the subject occupied the attention of the International Geographical Congress at Venice, at which a delegate from the Canadian Institute attended. The general question was warmly discussed and resolutions adopted. The appointment of an International Conference to meet at Washington, specially to consider the question, was then suggested by the Canadian delegate, and warmly supported by gentlemen representing the Government and scientic societies of the United States. The President of the Congress communicated the resolutions to the Italian Government, and Prince Teano, on behalf of the Italian Government, undertook to conduct the official correspondence. Out of this appears to have sprung the important discussion at the meeting of the International Geodetic Association at Rome, in October 1883, when the utility of Universal Time was recognized, and a special International Conference for the establishment of a zero-meridian for longitude and time recommended.

Returning to this side of the Atlantic, the question of regulating time for railway, telegraph, and civil purposes generally, was considered at the Convention of the American Society of Civil Engineers, held at Montreal, June 15, 1881, and a committee of men engaged in the management, and familiar with the economy of railways, appointed to examine the question. The committee has reported from time to time. They recognized that a proposition to reform the general time system of the country was a problem beset with difficulties, but it did not appear to them insolvable. It was felt, however, that the question affect so many interests that any change could only be effected by general concurrence.

To attain the end proposed by this society, the papers bearing on the question were printed, and a scheme modified on the "Proceedings" of the Canadian Institute was drawn up, under the title of "Cosmopolitan scheme for regulating time."

I may briefly recall the features of the scheme.

There should be one standard of absolute time, a Universal Day, based on the mean solar passage, at one particular meridian, the Prime or initial meridian for computing longitude. This Prime Meridian, together with the Universal Day, to be observed by all civilized nations.

There should be 24 secondary or hour-meridians established, 15 degrees of longitude apart, beginning with the Prime Meridian as zero.

To distinguish the Universal Day from

local days, it should bear the title of "Cosmic Day." *

Cosmic Time is intended to be used to promote exactness in chronology, and to be employed in astronomy, navigation, meteorology, and in synchronous observations throughout the world. To be employed in ocean telegraphy, and generally in all operations non-local in character.

The several 24 meridians to be used as standards for local time around the globe. Applying the system to North America, the effect would be to reduce the standards to four or five, as suggested by the Metrological Society.

A circular, dated March 15, 1882, signed by Mr. John Bogart, the Secretary of the American Society of Civil Engineers, was forwarded to the leading men in railway direction, either as general managers, superintendents, or engineers, and to men of scientific attainments throughout the United States and Canada. The paper thus circulated contained eleven questions, and categorical replies were invited to them.

Replies were received and reported on at a Convention of the Society, held in Washington on May 15, 1882. The scheme submitted was generally and cordially approved.

An emphatic and unanimous opinion was expressed, that there should be established as early as possible a comprehensive system of Standard Time for North America.

Of those who replied to the queries, 95 per cent. favored the idea that there should be a common agreement between the standards of time in all countries. That while we must primarily look to our own convenience on this continent, it is proper to aim at eventually attaining general uniformity among all nations.

Seventy-six per cent. were in favor of reducing the standards in North America so that they would differ only by intervals of one hour, and 92 per cent. were in favor of a notation of the hours of the day by a single series from 1 to 24, instead of in two divisions, each of 12 hours.

The character of the replies received indicated that a remarkable unanimity of opinion prevailed in every section of the continent heard from. The Convention accordingly resolved that an attempt should be made to obtain European concurrence to the selection of a Prime Meridian on which a time-system could be definitely based. But, failing to obtain this recognition, the people of the Western Continent should determine a zero-meridian for their own use and guidance.

It was thereupon resolved to petition the Congress of the United States to take the matter into consideration. The American Metrological Society about the same time adopted a similar proceeding. The consequences were that a joint resolution of the House of Representatives and the Senate was passed, authorizing the President of the United States to call an International Conference to fix on and recommend for universal adoption a common Prime Meridian to be used in the reckoning of longitude and in the regulation of time throughout the world.

On the meeting of the American Association for the Advancement of Science in Montreal, in July, 1882, the subject was brought forward, and all the documents were submitted and discussed. It was agreed that the Association should co-operate with other bodies in furtherance of the movement.

On two occasions the Royal Society of Canada has had its attention directed to the matter, and this body has assisted in furthering the determination of the problem by its co-operation and by correspondence with the Government.

While some delay took place in summoning the International Conference by the President, in consequence of diplomatic correspondence on the subject, the question was ripening on both sides of the Atlantic for concerted action. Indeed, a decision with respect to the regulation of local time was anticipated by the railway authorities in North America, who adopted the system of hour-standards which had been prominently brought forward as described.

On November 18th of last year (1883), the new system of regulating railway time on this continent came into opera-

* [*Note*—I may remark that the designation, "Cosmic," was first suggested, independently, by two Canadian gentlemen widely separated, by Mr. R. G Haliburton, then in Algiers, and by Mr. Thomas Hector, of Ottawa. The etymology commends the use of the word. It has been accepted by a number of societies and by many individuals as appropriate and applicable.]

tion. There had been several preliminary meetings of railway managers; the last meeting was a Convention held in Chicago the previous October, and it was then determined immediately to carry out the change.

Mr. W. F. Allen, the secretary of this Convention, who also took a prominent part in effecting the adoption of the change, has given a history of the events leading to it. Upon this gentleman mainly fell the labor of arranging details, and he executed the difficult duties assigned to him with consummate ability. In the words of the historian, the transition from the old to the new system "was put into effect without any appreciable jar, and without a single accident occurring." According to this authority the first newspaper to advocate some change was the *Railroad Gazette* for April 2d, 1870, and it is claimed that as early as 1869 Professor Charles F. Dowd, Principal of Temple Grove Ladies' Seminary, Saratoga Springs, proposed a system of meridians based on the meridian of Washington at intervals of one hour, by which railways should be operated, and that an expression of his views was placed in the hands of the President of the New York and Canada Railroad. The proposition appears to have attracted attention in the "Travelers' Official Guide" of 1872. In 1873 it was brought before the Railway Association of America, not now in existence. A committee was appointed to examine into its merits; they failed to recognize the necessity, and recommended that the question of National Standard Time for use on Railways be deferred till it more clearly appeared that the public interest called for it.

Mr. Dowd's efforts to introduce a National Standard Time to meet the difficulties which were being developed were at the time imperfectly appreciated. He, however, had the satisfaction of seeing a scheme unanimously accepted, and put in operation, which in essential features does not materially differ from that which he advocated; and he himself attended at the meeting of the American Metrological Society, and took part in the proceedings when the details of the new time arrangements were officially narrated.

Prominent among those who have earnestly labored to advance the movement of time reform is the distinguished President of Columbia College, New York. Dr. Barnard has from the first taken the deepest interest in the question, and few men have done so much to bring it to a practical issue. In the "Proceedings" of the American Metrological Society for 1881 will be found a paper prepared by Dr. Barnard in 1872, and presented to an association which has since assumed an international character, and is known as the Association for the Reform and Codification of the Laws of Nations. In this paper Dr. Barnard recommends the selection of Greenwich as the Prime Meridian for the world, and he submits the views he held at that early date, which at this hour are of peculiar interest. He points out that "it is becoming a matter of greater importance every day that there should be established some universal rule for defining the calendar day for all the world."

I have alluded to the valuable report of Professor Cleveland Abbe, of the United States Signal Service, to the Metrological Society, and I cannot deny myself the pleasure of acknowledging the services of the gentlemen with whom I have been associated on the special committee on Standard Time of the American Society of Civil Engineers, Mr. Charles Paine, of New York; Mr. Theodore N. Ely, of Altoona, Pennsylvania; Mr. J. M. Toucey, of the Hudson River Railway; Professor Hilgard, Coast Survey, Washington; Professor T. Egleston, of Columbia College; General T. G. Ellis, of Hartford, now unfortunately deceased, and Mr. John Bogart, Secretary of the Society.

The American Society of Civil Engineers, since meeting in Montreal, in 1881, has made persistent and continuous efforts in the common interest to advance the movement of time reform, having greatly aided in bringing about the important change carried into effect a year ago. This Society is now directing attention to a reform of scarcely less importance, the notation of the hours of the day. At the Buffalo Convention in June, 1884, this particular question received prominent consideration in the address of the President, as well as in the report of the special committee. Since that date a correspondence has taken place between the Secretary and the railway managers in the United States and Canada. Already replies have been received from the representatives of some 60,000 miles of railway, 98 per cent. of whom have given expression to their sympathy with the movement, to abandon the old practice of halving the day, designating the two sets of twelve hours by the abbreviations A. M. and P. M., and are prepared to adopt a simple notation of 1 to 24 in a single series. The great telegraph interests of the country are likewise in full sympathy with it. The President of the Western Union Telegraph Company, Dr. Norvin Green, states that their telegraphic traffic is equal to the transmission of 44,000,000 messages a year, and the general adoption of the 24 o'clock system (as it has been designated), would be cordially welcomed by telegraphers. It would reduce materially the risk of errors, and to the company over which he presides, he says it would save the transmission by telegraph of at least 150,000,000 letters annually.

The branch literature bearing on the two questions of Universal Time and the establishment of a Prime Meridian, has been enriched by a series of papers which have appeared during the past year in the *International Standard*, a magazine published in Cleveland, Ohio. These papers are by the following gentlemen, connected with the International Institute: Rev. H. G. Wood, of Sharon, Pennsylvania; Professor C. Piazzi-Smith, Astronomer Royal for Scotland; Professor John N. Stockwell, Astronomer, Cleveland; Mr. Jacob M. Clark, C. E., New York; Mr. William H. Searle, Pennsylvania; the late Abbe F. Moigno, Canon of St. Denis, Paris; Commodore Wm. B. Whiting, United States Navy; Mr. Charles Latimer, C. E., Cleveland, and others.

It will be seen from what I have submitted, that the proceedings have neither been few nor without success, and that since this Institute published the first issue of papers on Time and Time-reckoning, the subject has received much attention on both sides of the Atlantic. Societies with kindred pursuits, men of recognized merit in the scientific world, have turned to its examination and aided in its development. Some few men have acted in concert. The labors of others have been independent. Some of these names I have been able to record, but I fear that I neglect to include many of eminence because they are not known to me. It is this varied and widely diffused effort which has rendered possible the realization of the practical results which I have the gratification to record, and all the members of this Society must equally join in the common satisfaction in the measure of success which has been achieved.

Six years back, when the subject was discussed in this hall, there were probably not a few who viewed the propositions then submitted as merely fanciful theories. Others, who did not refuse to recognize their bearing, entertained the feeling that many grave difficulties presented themselves to interfere with any successful attempt to reform or modify usages so ancient as the computation of time. But the Institute, as a body, was hopeful. The action taken by the Council to extend the field of discussion and awaken the attention of foreign communities, evinced confidence, and we may now ask, was this confidence justified? What are the facts to-day? Twelve months have passed since an important change in the notation of railway time was made with general approval throughout the length and breadth of North America; a revolution in the usages of 60,000,000 of people has been silently effected and with scarcely a trace that it has happened. That proceeding has been followed by events of equal importance. On October 1st last, a body of accredited delegates from the different nations, on the invitation of the President of the United States, met in conference to consider the problem first submitted to the world by this Institute. The delegates were the representatives of 25 civilized nations. The Conference continued during the whole month of October, and, as a body, they came to conclusions affecting all peoples living under our theories of civilization.

It was early understood that a determination with respect to Universal Time was not possible without the general recognition of a Prime Meridian. Hence the importance attached to its choice, that it should be universally accepted.

It is stated that trials made of Natal coal on the local railway have ended satisfactorily.

THE ANTWERP TRAMWAY LOCOMOTIVE TRIALS.

From "The Engineer."

After a trial of four months with various kinds of mechanical motors, carried out with the appearance of conclusive exactness, the Antwerp jury have arrived at a decision concerning their award. This was mentioned by us last week without comment. An interesting paper on the results of the experiments was read before the Society of Arts, on the 20th inst., by Captain Douglas Galton, and this, while serving to demonstrate the satisfactory nature of the trial, in some respects, showed, on the other hand, what we may venture to call very insufficient evidence for arriving at a conclusion and making an award. The various systems of tramway haulage were insufficiently represented, and the arrangements for ascertaining the cost of working by electricity were very incomplete. The experiments lasted about four months. Five competitive systems offered themselves, which may be classed as follows: Three were propelled by the direct action of steam, and two were propelled by stored-up work supplied from fixed engines. The former were: (1) The Krauss locomotive engine, separate from the carriage. (2) The Wilkinson locomotive engine, *i. e.*, Black and Hawthorn —also separate from the carriage. (3) The Rowan engine and carriage combined. The second class, or those propelled by stored-up force, were: (4) The Beaumont compressed air car. (5) The electric car worked by a secondary battery of 2,464 lbs. weight. Captain Galton very mildly comments on the inadequacy of the range of the experiments when he says it is to be regretted in the public interest that other forms of mechanical motors, such as the Mekarski compressed-air engine, or the engine worked with superheated water, or cable tramways, or electrical tramways, were not also present for competition.

The engines named above include three out of the five known systems of tramcar haulage, only three being represented at Antwerp. The jury could not, of course, alter this or compel makers to attend or go to the expense of building a cable tramway. They might, however, have taken into consideration the fact that only half of the best systems of working tramways by mechanical power were represented at Antwerp. The experiments were made upon a line of tramway laid down for the purpose from near the main entrance of the Exhibition to the principal railway station, a distance of 2,292 meters, or 1.4 mile, beside which there was a triangle for turning of 500 meters, or 0.31 mile. Out of the whole length of the line, viz., 2,797 meters, 2,295 meters were in a straight line, 189 meters in curves of $1\frac{3}{4}$ chain radius, and 313 meters in curves of 1 chain radius. There were on the line four passing places, beside a passing place at the terminus; these were joined to the main line by curves of $1\frac{3}{4}$ chain radius. The line was practically level, the steepest incline being 1 in 1,000, so that the experiments cannot be said to have tested the capabilities of the motors for dealing with lines on which horse traction becomes most expensive.

A regular service was established according to a fixed time-table. Each journey was reckoned as starting from the end near the Exhibition, proceeding to the beginning of the triangle, and returning to the starting point. An hour was allowed between the commencement of each journey, fourteen minutes were allowed for a stoppage at the end near the Exhibition, and eighteen minutes at the other end—thus allowing twenty-eight minutes for traveling 2 miles 1,500 yards, or a traveling speed of about six miles an hour. The motors were require to work four days out of six, and on one of the four days to draw a supplementary carriage. The conditions and circumstances were thus of the easiest and in every respect of the most favorable kind. As an explanation of the fact that the cars ran only four days per week, it was explained that there was not room in the service for the cars to work more than this proportion of the whole time. It will thus be seen practically unlimited time was available for nursing any car or motor that needed it, and it is quite certain that the wealthiest tramway company could not afford to have as much plant standing idle as this represents.

A large number of conditions were laid down as requirements, but we need not refer to them here. We need only refer to those which tramway companies would have most to consider, and these will be gathered from the figures we will give from Captain Galton's paper, premising that all the cars satisfied the regulations concerning the emission of steam and smoke, brake power and appearance. The dead weights per paying load were: Electric car, 1.78; Rowan, 2.3; compressed-air, 2.55. In this comparison it is necessary to remember that both the Rowan and the Beaumont car possessed much greater power and range of power than the electric, both being made to deal with considerable gradients and heavy traffic.

The electric car stands first in respect of rapidity with which it can be brought into action from the shed, as it can receive its battery more rapidly than even the boiler for heating the compressed air could be got ready for use. The Rowan engine stands next, obtaining steam of 8 atmospheres in forty minutes, the Wilkinson requiring forty-seven minutes. In consumption of fuel per train mile, the Rowan stands first, using 5.42 lbs.; electric (estimated) 6.16; Wilkinson, 8.82; Krauss, 9.1; and the Beaumont, 39.48. The Rowan is, however, far ahead of the others in consumption of fuel per place indicated, per mile, using but 0.09 lb. per mile, the electric and the Wilkinson used 0.18, the Krauss 0.20, and the Beaumont 0.69; and the Rowan is still further ahead of the others in fuel per seat per mile run, allowing 16 in. per seat, using but 0.10, while the electric and the Wilkinson used 0.23, the Krauss 0.25, and the Beaumont 0.66. The Rowan and the electric were the same in consumption of oil and tallow, namely, 0.038 lb. per mile, the others being all much higher. The Rowan, having a condenser, was not only the most economical in fuel, but used only 0.75 gallon of water per mile, as compared with 1.06 by the Beamont compressed air, 5.89 by the Wilkinson, and 6.52 by the Krauss.

The consumption of fuel for the electric car cannot be taken as at all accurate, "because the engine which furnished the electricity to the motor also supplied electricity for electric lights, as well as for an experimental electric motor which was running on the lines of tramway, but was not brought into competition." Anyone who has had any experience of electricians' estimates of power used by them, will know that the above facts pretty considerably complicate the estimate, and go far to vitiate its value. The conclusion arrived at by Captain Douglas Galton, who was the English juror, is that the electric is undoubtedly the preferable tramway motor if it can be relied upon, and if the accumulators and machinery can be made durable in the service; and assuming this durability and trustworthiness, then the Rowan engine is the best under every consideration. In spite, however, of the unproved practicability in long and severe service, the jury have determined, we believe, to award the electric car the first prize and to give the Rowan a gold medal, a decision which does not seem to be supported by the results either of the trials or experience. There is no doubt that the electric car is very highly deserving of commendation; but why it has been placed first in the list of awards, except that it promises to suit Antwerp traffic very well, does not appear. The award has no value whatever in England, for it was arrived at without sufficient tests; and by comparison of only three out of six of the systems now in use; and if we consider the cable system and the electric system as now in operation at Blackpool, we must think that two of the most promising of all methods of tramway working were not included in the trials.

A NEWSPAPER correspondent describing the American watch manufactory at Waltham, Mass., and in speaking of the astonishing minuteness of some very essential parts of the watch, says:—"A small heap of grain was shown to us, looking like iron filings or grains of pepper from a pepper castor—apparently the mere dust of the machine which turned them out—and these, when examined with a microscope, were found to be perfect screws, each to be driven to its place with a screwdriver. It is one of the statistics at Waltham worth remembering that a single pound of steel, costing but 50 cents, is thus manufactured into 100,000 screws, which are worth 11 dollars."—*The Engineer*.

THE RELATIVE MERITS OF ELECTRICITY, GAS, AND OIL AS LIGHTHOUSE ILLUMINANTS.

From "Nature."

The Committee appointed by the Trinity House to report on the merits of electricity, gas and mineral oil as lighthouse illuminants have recently issued a valuable report giving an account of the investigations carried out under their directions, and the conclusions they have arrived at. The committee consisted of Elder Brethren of the Trinity House. They were assisted by Mr. A. Vernon Harcourt, who was appointed by the Board of Trade to co-operate with the Committee, and by Professor W. Grylls Adams and Mr. Harold Dixon, in the more purely scientific part of their investigation.

Three temporary lighthouses were erected on South Foreland, and fitted up for electricity, gas and mineral oil; the optical arrangements were "multiform" in all three—that is, consisted of several similar sources of light, each with its own condensing lenses, superposed; in the case of the electrical tower there were three superposed lamps, as was also the case with the oil tower; but in the gas tower there were four lamps; the two former were therefore "triform," whereas the latter was a "quadriform" light. Any one lamp in either tower could be lighted independently of the others, so as, for instance, to perform biform electricity to be compared with triform oil and quadriform gas.

The lamps for the electric light, and the magneto-electric machines for working them, were supplied by M. de Meritens; the gas apparatus was that of Mr. Wigham, each burner consisting of 108 jets in concentric rings, of which a part only might be employed; the oil lamps in the third tower during the greater part of the trials were six-wicked Douglass pattern, but burners of this description with seven and eight concentric wicks were also tried at various times during the progress of the experiments.

In addition to the temporary lighthouses, three observing huts and a photometric gallery 380 ft. long were erected.

The actual observations that were made may be divided into two classes—eye estimations, and photometric measurements. The former were made by the Elder Brethren, by officers on board the light vessels in the neighborhood, by merchant officers in passing ships, and by the coastguard officers at those stations from which the lights were visible. These eye observations were of two kinds—(1) Estimations of the comparative brilliancy of the lights; (2) definite statements as to the various distances at which the lights were visible in hazy or foggy weather.

With reference to observations of the first kind, they were conducted in accordance with regulations issued by the Trinity House Committee; the observers were instructed in filling in the books of forms which were issued to them, to put down in one column the light from the electrical tower as 100 and in the other column the estimated brilliancy of the lights exhibited by the other two towers as compared with it. It seems probable that the recorded numerical values of the relative brilliancy of the lights can only be a very rough approximation, and that the figures can hardly be taken as indicating with any degree of precision how much brighter one or other of the lights was on any particular occasion. This would probably be admitted by all who have any acquaintance with actual photometric measurements, and who therefore know how difficult it is to form any reliable judgment of the relative illumination of two surfaces, even when these surfaces are actually in contact, excepting the relation of equality. In the case of the experimental lights the comparison must have been rendered still more difficult by the fact that what was to be compared was not the comparative illumination of two moderately bright surfaces in close proximity, but the comparative brilliancy of two lights at some distance from each other, their very brightness adding to the difficulty.

Still, these estimations are manifestly

valuable as setting forth in a clear and unmistakable form that, to the average observer, a particular light appeared the most brilliant; and such seems to have been the way in which they were regarded by the Committee, for on page 21 they state "it will be evident that by mere eye-measurement proportions can only be approximately determined, although the order of superiority may be accepted as proved."

The results of these determinations are set forth in four tables, from which it appears that in clear weather, and in weather that, although not absolutely clear, was not very foggy, there was no question as to the absolute superiority of the electric light over both its competitors, the electric light in the single form having a superiority of more than 30 per cent. assigned to it, as over gas, or oil, in their highest powers (*i. e.*, quadriform for gas, and, triform for oil); the large-sized gas-burner, with 108 jets, appears to have been slightly superior to the six-wick oil-burner, and, consequently, the quadriform gas to the triform oil.

The eye observations of the second kind, those in which the distances at which the lights were visible in foggy weather were recorded, gave much the same result; that the electric light penetrated through the fog to the greatest distance, and that the oil and the gas were about equal in their penetrating power.

These observations also showed that in the case of the electricity the best result was obtained when the currents produced by two or even three machines were sent through a single lamp, and not when each of the lamps was worked by its own special current.

The photometric measurements were carried out by Mr. Dixon, Mr. Harcourt's pentane flame being used as the standard. As is well known, Mr. Harcourt's standard is an air-gas flame which, unlike the so-called standard candles still commonly used for photometric purposes, is not subject to irregular variations in its light-producing powers. Part II. of the Report contains a full account of the standard flame, and the two arrangements for producing it, both of which were in use at the South Foreland. In Mr. Harcourt's original arrangement the air-gas was made and stored in a gas-holder by causing a volume of pentane to diffuse into a known volume of air, and then burning the mixture under certain definite conditions which could be accurately produced at all times. The conditions were such that the flame emitted the same amount of light as an average sperm candle burning under the conditions laid down in the Acts of Parliament which control the quality of the metropolitan gas supply, an amount of light which may differ considerably from that emitted by any single candle.

Mr. Harcourt's pentane lamp was also used; in this arrangement the air-gas is produced as it is required. The lamp is very simple in construction, and the flame is just as constant as in the older form, and as easily regulated, whilst, unlike the older form, the lamp is extremely portable, the whole apparatus not occupying much more space than a packet of candles.

Two kinds of photometer were used—a bar photometer with a Leeson star disk, and Mr. Harcourt's table photometer. The latter is a variety of shadow photometer, and possesses two special advantages—(1) In common with all shadow photometers the two sources of light are on the same side of the illuminated surface, and therefore there is less risk of the results being rendered untrustworthy by diffused or accidentally reflected light than when, as in the more commonly employed arrangements, the sources of light are on opposite sides. (2) The comparison being made by altering the size of the flames, and not their distance, the two portions of the illuminated surface do not alter their relative position, and are always in that which is most favorable for comparison, accurate juxtaposition. The difference in color between the arc light and the pentane rendered it impossible to employ the shadow photometer for the estimation of the electric light. For these measurements a Leeson star disk was employed, and it was found that reliable measurements could be obtained by placing the disk between the two lights and moving it to and fro until a pattern of the star was equally distinct on either side, although on the two sides the colors of the pattern and the background were reversed.

There was so little difference between

the color of the gas and oil flames, and that of the pentane flame, that in the case of these two illuminants measurements could be made both with the star disk and with the shadow photometer.

Comparisons were made in the photometric shed of the light emitted by the De Meritens electric lamp; the Wigham gas burners with different numbers of jets up to the maximum of 108, the Douglass Argand gas-burner, the Sugg gas-burner, and the Siemens regenerative gas-burner, and also the six and seven-wick Douglass oil-burners.

The amount of light emitted by each of the experimental lighthouses was also determined, the observations being made in the huts which had been erected for this purpose at different distances from the towers. At the hut nearest to the towers, the light from all the burners could be compared directly with the pentane lamp giving the light of one candle, but at the second hut only the electric light and the higher powers of the gas and oil lights could be directly compared with the pentane lamp; the single gas and oil lights had to be condensed by a lens before accurate measurements of them could be taken; an achromatic lens, lent by the Astronomer Royal, was used for this purpose. The fraction of the light lost by the absorption and reflection of the lens was experimentally determined and allowed for in the observation.

The general result of a very large number of observations appears to have been that there is but little to choose between oil and gas, as far as their illuminating powers are concerned, and that electricity is greatly superior to both.

The experiments brought out one fact of great practical, as well as scientific interest—that remarkable changes in the transparency of the air occur without any visible haze or mist. To quote Mr. Dixon's words—"Invisible clouds seemed to float by, obscuring the lights for a time as they passed across our line of vision. Sometimes the French lights at Calais and Cape Grisnez showed brilliantly, when the photometer at Hut 2 proved that the lights from the experimental towers, only a mile and a quarter away, had lost one-fourth to one-third their power."

With a view of further investigating the fog-penetrating powers of these different lights, the photometer shed was filled with an artificial steam fog, by means of a pipe brought from the boiler of the engine-house, and the 108-jet Wigham gas-burner, and an electric arc fed by one machine, were pitted against each other, and the distances from which the lights could be seen determined. In all cases the electric arc became visible before the gas flame, as the observers walked up the shed towards the lights, confirming the other eye-observations which have been already mentioned.

The experiments showed also that the electric light suffered a greater proportional loss than either of the two other illuminants when passing through fog or haze, but that, owing to its far greater initial intensity, it nevertheless exceeded the other lights in its penetrating power.

The Committee add to their report some account of the cost of the three illuminants, from which it appears that there is but little difference in the first cost of the electric and gas systems, the latter being slightly the more costly; but, on the other hand, the annual cost of the gas is estimated at rather less than that of the electricity. The cost of the mineral oil apparatus is estimated, both for its installation and for its annual maintenance, at about two-thirds that of either gas or electricity.

The general conclusions arrived at by the Committee—conclusions which seem fully borne out by the evidence set forth in the report—are, that the "electric light, as exhibited in the experimental tower at South Foreland, has proved to be the most powerful light under all conditions of weather, and to have the greatest penetrative power in fog"; that for all practical purposes the gas and oil were equal; and "that for the ordinary necessities of lighthouse illumination, mineral oil is the most suitable and economical illuminant, and that for salient headlands, important landfalls, and places where a very powerful light is required, electricity offers the greatest advantages."

German Steel Rails.—The Rhine Steel Works Company has obtained an order for 1,500 tons of steel rails for Spain. The same company and the Bochum Steel Works Company have secured orders for steel rails for the Swedish State lines, 2,000 tons and 4,500 tons respectively.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers—Annual Meeting January 20th–21st.—The Annual Meeting of Society was called to order at 10 o'clock, Weduesday, January 20th, President Frederic Graff in the chair. Messrs. Charles H. Swan, J. F. Flagg, Robert Cartwright, aud F. C. Prindle were appointed tellers to canvass the vote for officers of the Society.

The Report of the Board of Direction for the year ending December 31st, 1885, was presented. There has been during the year an addition of 74 to the various grades of membership in the Society, viz., 56 members, 2 associates, 15 juniors, and 1 fellow. Three juniors were transferred to members. There have been 12 deaths, 5 resignatious, and 4 have beeu dropped from the rolls. Reference was made iu the report to the successful conveution held at Deer Park, Md., June, 1885; also to the fact that the attendance at other meetings of the Society during the year has been larger than ever before, and that very many non-resident members have been present at such meetings. The collations and informal receptions held after the meetiugs on the first of each month have provided opportunities for intercourse between members and visiting engineers which would uot otherwise have occurred. The collatious have been furnished by subscriptions from resident members. No funds of the Society have been used for this purpose.

The "Transactions and Proceedings" for 1885 contain some 160 pages more thau have ever been issued in any previous year. The Board devotes the larger part of the iucome of the Society to the preparation and issue of these publications.

There have been but two contributions to the building fund during the year. Every coutributiou to this fuud reduces the reutal paid by the Society for its house, which rental is now in the form of interest on the mortgage aud taxes on the property. The house itself is au excellent investment, steadily increasing in value. The Board calls the attention of members to the desirability of reducing the mortgage upou the property by contributions to the building fund from persons interested in the welfare of the Society. During the year but one fellow was elected. The Board refers to the fact that association with the Society as a fellow secures all the publications and a participation in all the privileges, except the right to vote, and that the suggestion of such association with the Society, to many gentlemen not otherwise connected with it, might result in a large increase of this important fund, the iucome from which is devoted to the publications. The fellowship subscriptiou is, at present, $150 for life.

The only amendment to the Constitution passed during the year was one providing for the compoundiug for future annual dues by a single payment.

The Board of Censors to award the Norman Medal for the past year, reports the award of that medal to paper No. 300, "Record of Tests of Cement made for the Boston Main Drainage Works, 1878–1884," by Elliot C. Clarke, M. Am. Soc. C. E. The committee to award the Rowland Prize for the past year report the award of that prize to paper No. 295, "Experiments with New Apparatus at Low Velocities," by A. M. Wellington, M. Am. Soc. C. E.

The committee appointed to confer with committees appointed by kindred societies for the purpose of devising and considering a plan for creating a library for the joint use of the organizations represented, reported that meetings had been held with committees from the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers; that the members of the joint committee are practically in accord as to the desirability of the joint library and as to the geueral plan to be adopted. The committee is encouraged with the prospect of success in securing a plan capable of executiou, but is not yet prepared to report in detail. The report was accepted and the committee contiuued.

The committee on Uniform Standard Time reported that practical progress was being made in the direction of notation of the hours from one to twenty-four, and the abandonment of the division of the day into half days; that many important railways were ready to co-operate in this direction, and that it had beeu publicly announced that the Canadian Pacific Railway was prepared to make this chauge at an early day. The report was accepted, and the committee coutinued.

The committee on the Compressive Strength of Cements, and the Compression of Cements and the Settlemeut of Masonry, reported the organization of the committee and the commencement of investigation of the subject. The committee was continued.

A report from a minority of the committee to Consider changes in the Organization of the Society was presented. No report from the majority was presented. The whole subject was referred back to the committee.

The tellers appointed to canvass the ballot for officers of the Society reported the result of the canvass, and the following members were declared elected officers of the Society for the ensuing year: President, Henry Flad; Vice-Presideuts, Thomas F. Rowland and Thomas C. Keefer; Secretary and Librarian, John Bogart; Treasurer, J. James R. Croes; Directors, G. S. Greene, Jr., William R. Hutton, W. Howard White, Henry G. Morris, and Charles L. Strobel.

February 3d, 1886.—Vice-President Thomas F. Rowland in the chair. The following candidates were elected as members: Edward Wm. Eckert, Massillon, Ohio; James Ellison Mills, Quiucy, Ill.; Edward Thomas Wright, Los Angeles, Cal. As associates—George Lord Burrows, Sagiuaw, Mich.; Palmer Chamberlaine Ricketts, Troy, N. Y.

A paper by T. H McKenzie, M. Am. Soc. C. E., on the "Water-works of Southington, Connecticut," was read. The town of Southington is on the Qununpiac River, in a valley surrounded by hills rising 600 feet above the river. The water-works were constructed by a private corporation iu 1883–84. The water is procured from a mountain stream with a drainage-way of $2\frac{1}{2}$ square miles, mostly inclined and with regular surface. The rock is granite. The storage reservoir is formed by an earth dam, 4 miles from and 535 feet above the town. The distributing reservoir is built about 3 miles from the town, and 240 feet above it; the water is conveyed from this reservoir by a cast-iron pipe. The gaugings of the stream during 1883 showed an average daily flow of 4,300,000 gallons. The storage reservoir covers an area of 23 acres, has 25 feet depth of water at the dam, and a capacity of 60,000,000 gallons. The earth for the dam was of solid loam, placed in horizontal layers not more than 6 in. in depth, and each layer wet and rolled with a 3-ton grooved iron roller. A 20-in. cast-iron pipe is laid through the dam on a heavy masonry wall for its entire length, with short cut-off walls every 24 feet. At the outlet of the pipe a heavy masonry apron, with wing-walls, is built on the bed rock.

The distributing reservoir is formed by a masonry dam 20 ft. in height, which covers an area of $1\frac{1}{2}$ acres, and contains 3,000,000 gallons.

The main supply-pipe through the dam is 12 in. in diameter, and from thence to the town 10 in.; the general depth is $5\frac{1}{2}$ ft. It is all carefully laid to grade with very few horizontal bends; there are no vertical bends, except at the four summits, where air-cocks are placed. There are blow-offs at each depression of the grade. Thickness and weight of pipe are adjusted to the pressure to each 100 ft. of head. The pipes are coated by immersion in a bath of heated coal-tar pitch, and were tested to a pressure of 300 lbs. per square inch. The distribution pipes, 8, 6, and 4 in. in diameter, are laid to grade, and at all summits house supply pipes are arranged to act as air-vents. The pressure over most of the town ranges from 90 to 100 pounds. Hydrants are set at all corners, and also at other points, so that they are not more than 500 ft. apart. The whole cost of the works was $88,750, which is moderate, as compared with many other similar works. No leaks have appeared, and no fissures of any kind have occurred in the dams, pipes, or fixtures.

Engineers' Club of Philadelphia—Record of Regular Meeting, January 16th, 1886.—Mr. Howard Constable gave an interesting account of the system used in London for the Public Supply of Hydraulic Power, which he has recently had occasion to examine. The company in London was started in 1882, based upon the success achieved by a similar scheme in Hull, which has been in operation some eight years; it, in turn, was the outgrowth of a system which prevails very extensively in many English manufacturing and warehouse concerns—that of employing hydraulic cranes, hoist capstans, and the like, and operating them from one pumping station. This plan was advocated by Mr. Bramah as early as 1802, and during the past forty years Sir William Armstrong has done much towards putting it into practice by the manufacture of hydraulic plant, so that the advantages of the principle are much more thoroughly understood abroad than with us, The general mind in this country looks with some fear upon high pressures, and thinks the system rather novel, not knowing that in our practice of pumping oil to the seaboard, pressing cotton and extracting oil from seeds, we employ hydraulic pressures ranging all the way from 400 to 5,000 lbs., and over, per square inch, whereas the London Supply Co. use only 700 to 800 lbs.

Their plant consists of about 12 miles of cast-iron mains, distributed throughout the busiest parts of London, on both sides of the river, and as far west as Victoria Station. The mains and branches are laid so as to avoid any dead-ends, and with stop-valves so that any length of 1,000 ft. can be isolated. The water used is taken from the Thames and filtered into tanks, from which it is received by the pumps and passed into two accumulators, thence on through the mains. The pumps are of the vertical, three-cylinder, fly-wheel type, compound-condensing, single-acting plungers, directly connected to piston-rod. The starting and stopping of the pumps is done automatically by the accumulators; and in connection with this, the arrangements for letting live steam into the low-pressure cylinder is very ingenious. The boilers are of the Lancashire type, fitted out with automatic fuel-hoppers, stokers, etc., and fuel elevator. The charges for power water are made upon meter register and a sliding scale of prices. The financial success of the company was almost assured from the first.

Prof. T. M. Haupt read a profusely illustrated paper on Harbors, containing data as to depths, etc., and showing that from New York to the Gulf there were only four natural entrances where the depth at mean low water was over 16 ft., while the largest ships draw from 26 to $28\frac{1}{2}$ ft. He discussed the relation of the forces, stated the general principles to be observed in harbor improvements, commented on the unfavorable results obtained by using submerged jetties, and the reasons therefor, and called attention to a few special cases, which were reserved for a more complete discussion subsequently. A model was also shown, exhibiting a portion of the bed of the lower bay of New York entrance, with the peculiar hole at the head of Gedney's Channel, with an explanation of the forces which had maintained it for many years. He also stated that he believed it entirely feasible to so modify the forces as to change the direction of the resultant and throw it into Gedney's Channel. By such a local treatment an excellent entrance could be obtained to the harbor, at a cost very much less than that proposed to be expended for the submerged dykes—five miles long—and other works, estimated at five to six millions. The various features were freely illustrated by U. S. C. & G. S. and other diagrams.

February 6th, 1886.—The Secretary presented, for Mr. A. R. Cruse, a compilation of tests of the efficiency and economy of various gas burners.

The Secretary presented, for Mr. Mataro Crizuka, a paper, illustrated by Japanese map, upon the Railways in Japan. The history of the present railways is given, and the projects for the future. The paper treats of costs per mile; the bridges, tunnels, shops, etc.; the methods of operation, the profits of the traffic, the native and foreign supervision and labor, and the relations of the Government and private enterprise to the work.

Prof. L. M. Haupt read a second paper on Harbor Studies, discussing the action of tidal currents, and showing their locus as revealed by the mold of the harbor and the divide or crest line of the bars. He believed that local efforts to improve the channel across the New York bar would be most successful by utilizing the resulting ebb's scour at the head of Gedney's Channel by floating devices for concentration and vertical deflection of the currents there existing, and made a few remarks showing how such floating deflectors might be used to regulate the currents of the Mississippi River and so tend to establish a constant regimen.

Mr. J. Foster Crowell read a paper upon the Present Situation of the Interoceanic Canal Question, presenting the subject from a general standpoint. He sketched the history of the various past attempts to establish communication through the American Isthmus, and traced the developments in the different directions of effort, which finally concentrated the problem upon the three projects now before the world, summarizing the progress in each case, and stating the following propositions:

I. That Panama is the only possible site for a sea-level canal, and that such treatment is the only feasible method at that place.

II. The Nicaragua is the only practicable site for a slack-water system (for a canal with locks), and that it is pre-eminently adapted by nature for such a use; that there are no obstacles in an engineering sense, and no physical drawbacks that need deter the undertaking.

III. That the Ship Railway, as a mechanical contrivance, has the endorsement of the best authorities, and may be admitted to be the *ne plus ultra* as a means of taking ships from their natural element and transporting them over the land.

IV. That none of these plans has as yet advanced sufficiently to warrant our considering its completion as beyond doubt.

V. That, as the *additional* sum now asked for by De Lesseps (*even if sufficient*) to complete the Panama Canal, is *greater* than the estimated cost of either Nicaragua Canal or the Ship Railway, it would be economical to abandon the Panama Canal, and the money sunk in it, to date, unless its location and form possess paramount advantages, and we therefore may profitably consider the relative merits of the three lines, without regard to the past, from four standpoints, viz.:

1. Geographical convenience of location.
2. Adaptiveness to all marine requirements, present and future.
3. Political security.
4. Economy of construction and operation.

He then discussed the comparative claims to excellence. In the first consideration, after classifying the several grand divisions of future ocean traffic, and noting especially the needs of the United States, he claimed that, while there was little to choose, in this respect, between Nicaragua and Tehuantepec, either was far superior to Panama.

In the second particular he maintained that, owing to the characteristics of the Panama Canal and the practical impossibility of enlarging it hereafter, excepting at stupendous cost, it could not serve the purposes of the future, although it might, if completed, supply present need. He praised the ingenuity of the plans for the Ship Railway, but emphasized the fact that it will be the *movement of the traffic*, not merely the lifting and supporting of ships in transit, that will test the system, and suggested that even the beautiful application of mechanical force which had been contrived might be powerless to insure the high grade of service which is an absolute necessity. In this connection the general features of the Nicaragua Canal, in its latest form were referred to, and the opinion expressed that even were all difficulties in the way of the Ship Railway eliminated, it could not be superior to the canal in respect of adaptiveness.

In point of political security he claimed that both Tehuantepec and Nicaragua were reasonably free from doubts, with the advantage in favor of the latter, while at Panama no security, for United States interests at least, could be counted on, without the liability of a military expenditure far exceeding the cost of the canal itself.

The matter of comparative cost of construction and operation was discussed generally, and in conclusion the author stated that "this all-important question is still an open one, of which the future needs of our country justify and demand at this time a most searching scrutiny, and, moreover, our interest and the interest of mankind require that before this century closes, the best possible pathway between the Atlantic and the Pacific shall be open to the navies of the world.

The paper was illustrated with maps and diagrams.

ENGINEERING NOTES.

The Cleansing and Ventilation of Sewers.—At a recent meeting of the Metropolitan Board of Works a report was presented by the Sanitary Committee, making the following recommendations:

1. That any old and defective, disused, or partially disused sewers which may remain in any part of the metropolis should be disconnected from the present sewerage system, cleansed, and filled up; and that, where necessary, pipe or other proper sewers should be substituted.

2. That stringent measures be taken by the Board, and by the Vestries and District Boards (*a*) for preventing road-sweepings passing into sewers, (*b*) for preventing the discharge into sewers from manufactories and other places of improper substances, such as chemical refuse or trade filth, or of hot water or steam, so as to be the cause of nuisance.

3. That the most important requirement for keeping sewers in satisfactory condition is a supply of water sufficient in quantity to carry the sewage in suspension through the sewers.

4. That whenever the supply of water in

sewers is insufficient for cleansing the sewers, effectual provision for cleansing such sewers should be adopted by flushing or other means.

5. That one of the most effectual methods of flushing would be by means of water simultaneously discharged into house drains, as such a simultaneous discharge would flush branch sewers, then local sewers, and finally main sewers; that such a method of flushing can be effectually carried out by householders flushing their house drains periodically and simultaneously at stated times; that a great number of householders would probably be willing to co-operate with the authorities in improving the condition of the sewers in their district in this way; and that it is desirable that the several Vestries and District Boards should intimate upon what days and at what hours householders should flush their drains.

6. That provision near the heads of branch sewers, for flushing such sewers from their commencement, is to be desired.

7. That the practice of flushing the courts, alleys, small streets, etc., in poor districts in summer, is to be highly recommended as a desirable method of flushing sewers and improving the sanitary condition of the districts.

8. That next to effectual cleansing, one of the most important safeguards against nuisance and danger to health from sewers, is the dilution of the gases therein by a constant and plentiful supply of fresh air to the sewers by means of effective ventilation.

9. That the ventilation of sewers in the metropolis by means of ventilating shafts leading to gratings in the center of roadways, has been the cause of complaint, owing to the imperfect manner in which the system has been carried out, the ventilators being deficient both in size and number.

10. That the surface ventilators to the recently-constructed sewers have ordinarily been placed at a distance of from 50 to 60 yards apart, with air openings in the gratings equal to 60 square inches, and that the number and size of many of the ventilators on other sewers in the metropolis should be increased.

11. That the amount of ventilation afforded by large special ventilating shafts is in no way commensurate with their cost, and that the adoption of such shafts, with or without fire heat, or the connection of sewers with factory shafts can only be adopted in very exceptional circumstances. Where shafts with fires are used, the sewer gases should be allowed to pass into such shafts over as well as through the fires; otherwise the amount of ventilation afforded will be very much limited.

12. That pipe ventilators of large section, and constructed with bends and without angles, can be used with great advantage in addition to, and not in substitution for, surface ventilators, wherever the consent of owners and occupiers can be obtained to such ventilators being affixed.

13. That the Committee are of opinion that the ventilation of the sewers of the metropolis may be improved by altering the construction of many of the surface ventilators as previously recommended, and by carrying up large pipe ventilators at convenient points wherever practicable.

14. That the use of charcoal or other appliances for deodorizing gases in sewer ventilators is undesirable, as such appliances do much harm by obstructing ventilation, are costly and troublesome, and are quite unsuitable for general use over a large sewerage system.

15. That during the cold and wet seasons the arrangements suggested in the report for providing ventilation will be sufficient, as putrefaction proceeds so slowly at low temperatures, and when the sewage is diluted with large volumes of fresh water, that the foul matters pass from the sewers before material quantities of offensive gases are generated.

16. That during dry and hot weather the foregoing recommendations respecting the flushing and cleansing be carried out as far as practicable, especially in sewers having only a small flow of water.

17. That in addition to these precautions, a system of deodorization during the summer be arranged for the main sewers, on the plan adopted by the Board during the past summer; that local boards be requested to adopt a similar system with local sewers, and to use all their influence to induce householders to employ in their house drains suitable deodorizing agents during periods of high temperature and drought.

18. That manufacturers and others discharging refuse into the sewers be compelled to so treat their waste water (by such process as they may deem fit, but to the Board's satisfaction), that it shall have no greater *deoxidizing* power than average household sewage.

19. That the Committee are not prepared to recommend the Board to exercise the powers given by the 83d section of the Metropolis Management Amendment Act for making by-laws for the guidance, direction, and control of the vestries and district boards, and other persons in relation to the maintenance, cleansing, ventilation, etc., of sewers, until it is shown that the suggestions made in the report have not been voluntarily adopted.—*Building News.*

A WORK of considerable engineering importance, involving the diversion of the Spey was completed on Tuesday, in connection with a new line along the coast of Banff and Elgin. The Great Northern Railway Company of Scotland found it necessary to construct a bridge across the river about two miles from the mouth. The contractors had to construct the bridge at a point which rendered it necessary to divert the course of the river. It was done by opening a new bed to the left of the old one. Into this bed the water burst on Saturday rather unexpectedly. A great body of water still flowed in the old course, and to prevent this it was decided to form a huge dyke. Bags filled with sand were piled high up against the bed, but these were swept away, as the river narrowed, and the water cut a course 10 ft. where previously it had only been 4 ft. deep. The sand bags were then chained together in twenties, and dropped into the water. After continuous labor for a week, the work was completed on Tuesday, and the whole body of water now flows under the new bridge.

IRON AND STEEL NOTES.

From statistics just published it appears that the production of all descriptions of steel in the United States since 1874 has been as follows: 1874, 241,614 net tons; 1875, 436,575 tons; 1876, 597,174 tons; 1877, 637,972 tons; 1878, 819,814 tons; 1879, 1,047,586 tons; 1880, 1,397,015 tons; 1881, 1,778,912 tons; 1882, 1,945,095 tons; 1883, 1,874,359 tons; 1884, 1,736,985. The principal steel manufacturing State of the Union is Pennsylvania, which, of the 1,736,985 tons of steel made last year, produced 1,157.376 tons.

RAILWAY NOTES.

Automatic Brakes.—Continental railway companies, like some of those in this country, continue to afford practical illustrations of the advantages of really efficient brakes. Recently, near Courtrai, on the Belgian State Railway, the engine of an express train left the rails, causing the coupling to snap, and the Westinghouse brake to be automatically applied, thus avoiding most serious consequences. Again, at Thalhausen, on the Wurtemburg State Railway, the express train from Berlin to Milan had a very narrow escape indeed from being thrown into the river Neckar, from a cause which was at one time a fruitful source of disaster in this country. To shunt a wagon into a siding, leave the points open, and take off the main-line signals for an express train running at forty-five or fifty miles an hour, certainly affords an excellent chance of calamitous results ensuing, and these were only prevented on this occasion by the driver observing that the points were open and applying the Westinghouse brake, by which means the train was brought to a stand in the siding only two or three yards from the edge of the steep bank to the river. A further illustration comes to hand from France. The Indian mail, when running at forty-five miles per hour, left the line near Aiguelielle, on the Paris, Lyons, and Mediterranean Railway between Modane and Chambery, it is supposed owing to the spreading of the permanent way. Once more the engine separated from the train, and again the Westinghouse brake was applied automatically, the train being brought to a stand without injury to a single passenger. It will be noted that these accidents were all of that sudden emergency type which we have frequently pointed out is now, and will continue to be, the chief feature of our railway accidents. For such cases it is not sufficient simply to provide a continuous brake. It is perfectly clear that had the brake in either of these three instances given, not been powerful, instantaneous and automatic as well as continuous, it could have been of but little use in averting the terrible results which must almost inevitably have followed in every case. Fortunately, although opinions on the brake question differ on the Continent as to some points, there would appear to be an almost universal feeling in favor of automaticity and high pressure, as against simple brakes and those worked by vacuum, thus agreeing with the practice in America and the Colonies. At a recent meeting of the Society of German Mechanical Engineers at Berlin, a paper was read on the automatic vacuum brake, and some of our own railway companies would do well to weigh the remarks of Privy Councillor Stamke, Chief Technical Adviser of the Minister of Prussian railways. In the discussion which took place this influential official stated that it was quite useless to discuss vacuum brakes, since there could no longer be any question that automatic compressed-air brakes alone would be used over the whole Continent. This opinion receives some confirmation from the fact that it has just been decided to replace the vacuum brake by the Westinghouse on the Rome-Naples section of the Italian-Mediterranean Railway.—*Building News.*

ORDNANCE AND NAVAL.

Armor-plated Turrets.—The experiments which have just been concluded at Bucharest with the cupola turrets of the future fortifications of the Roumanian capital deserve attention for various reasons, the principal one of which is tnat they involved a trial of strength between the competing German and French systems. They also excited more than usual interest on account of a report to the effect that General Brialmont, the well-known Belgian engineer officer, who is charged with superintending the construction of those fortifications, had declined to undertake that duty unless the German style of turret was adopted. The unexpected results—unexpected because so much was anticipated from the French turrets—seem to indicate that General Brialmont was right. It appears to have been a foregone conclusion with the Roumanian military authorities that the German turret plates, manufactured by the well-known firm of armor-plate makers of H. Gruson, of Buckau, near Magdeburg, would have no chance against the French plates, supplied by the Société de Saint-Chamond (department of the Loire), when submitted to equally severe tests. The results have falsified the expectations or predilections of those most nearly concerned. Before giving those results, it should be stated that it is intended to convert Bucharest into a *place d'armes* of the first rank, by surrounding it with a girdle of fortifications between 37 and 44 miles long, and consisting of eighteen forts of three degrees of strength. The chief point of strength of the principal fort is to be forty revolving ironclad turrets, distributed amongst the forts, and each armed with two 15-centimeter guns. Having regard to the immense strides made by the artillery of the present day, owing to the introduction of chilled shot and rolled iron, as well as of long-range guns, and the progress achieved in the manufacture of iron armor for ships and land batteries, the decision respecting the turret system was made dependent, at the suggestion of General Brialmont, upon the competitive trials which have taken place, and the importance of which was enhanced by the presence not only of the military representatives of the great powers, but of officers of the Dutch, Danish, and Chinese armies. The respective turrets of the rival manufacturers were erected on the plateau of Cotroceni, near Bucharest, and armed with Krupp and De Bange guns and mortars respectively. It ought to be added that the system adopted in the French turret is that of Major Mougin, of the French engineers, and in the German turret that of Major Schumann, of the German engineers. At the beginning of the trials public opinion was on the side of the French system, and this appeared to be justified by the reports of the first few days' work. According to them, the French turret, notwithstanding its greater weight, revolved much more easily and more quickly than the lighter German turret. That statement was quite correct, and it was also a fact that the Krupp guns of the Schumann-Gruson turret had nine missfires in the first twenty-five rounds of two guns each, whilst the Bange guns in the French turret fired all the fifty rounds without a hitch. During the following days, however, the Krupp guns, provided with friction fuzes, worked as satisfactorily as the De Bange battery, furnished with electric fuzes, if the quick-match was pulled properly. Although during salvo target firing the Schumann turret could only fire forty-one rounds, more hits were obtained from it than from the Mougin turret with fifty rounds. In quick firing, the German turret fired the salvoes in thirteen minutes, whilst the French turret took twenty-one minutes. The battery of the German turret also excelled that of the French turret in firing at an unknown target indicated by hoisting and as quickly dropping a signaling flag. Still more favorable results were registered for the Schumann-Gruson turret system when the two revolving turrets served as targets to a battery of 15-centimeter Krupp hooped guns, fired at a distance of 1,000 meters. In order to strike the French turret thirty times, only forty-seven rounds had to be fired, whilst, to obtain a like number of hits of the German turret, which is provided with a flat dome, eighty-seven rounds had to be discharged. The mantle of the French turret, consisting of rolled iron 40 centimeters thick, has, besides, suffered considerably by the bombardment, a piece of iron weighing 6 cwt., besides several smaller fragments, having been detached from the enormous iron mantle of the Mougin turret. The German turret, with the exception of a small crack, has not been injured. The firing from mortars and the blasting experiments with dynamite carried on against the enormous chilled hoops outside the base of the two turrets having also resulted in a victory for the German turret, no surprise will be felt when it is stated that the commission of experts have pronounced in favor of the turrets on the Schumann-Gruson principle, and that the French turret has been discarded. General Brialmont's views on the subject have thus been fully sustained, notwithstanding that popular opinion was at first adverse to him. It is stated that the work of fortification of the Roumanian capital is to be proceeded with as soon as provision is made for the large funds required for carrying out the stupendous undertaking, the completion of which will convert Bucharest into the most formidable entrenched camp, next to Paris, in existence.—*Morning Post.*

BOOK NOTICES.

Publications Received.

Papers of the Institution of Civil Engineers: No. 1,995.—The Energy of Fuel in Locomotive Engines. By Granville Carlyle Cunningham, M. Inst. C. E.

No. 2,050.—The Karachi Water-works. By James Strachan, M. Inst. C. E.

No. 2,099.—Concrete Building at Simla, India. By Walter Smith, Assoc. M. Inst. C. E.

No. 2,111.—On an Improved Method of Lighting Vessels Under Way at Night. By Bradford Leslie, M. Inst. C. E.

Abstracts of Papers in Foreign Transactions and Periodicals.

The following Professional Papers of the Navy Department. After No. 12 the series has been known and styled "Naval Professional Papers":

1. Astronomy. By Prof. Chaunnet.
2. Tides and Tidal Phenomena. By Henry Mitchell.
3. Lightning Conductors. Translated from the French by Commander R. Aulick, U. S. N.
4. Report of the Circumnavigation Committee of the Royal Society, 1872.
5. The Marine Compass. By Prof. B. F. Greene, U. S. N.
6. Chronometer Rates. By Lt.-Com. C. H. Davis, Jr., U. S. N.
7. Lecture on the Turning Power of Ships. By W. H. White, R. N.
8. Observations for Dip taken on board the U. S. S. *Adams*. By Commander J. A. Howell, U. S. N.
9. Determination of the Length of a Nautical Mile. By Prof. J E. Hilgard, Supt. U. S. Coast Survey.
10. Iron Ships (Papers and Discussions). Reprinted from "Transactions of the Institution of Naval Architects,"
11. Steel for Ship-Building. Reprinted from "Transactions of the Institution of Naval Architects."
12. Screw Propulsion. Reprinted from the "Transactions of the Institution of Naval Architects."
13. Magnetism; Its General Principles and Special Application to Ships and Compasses.
14. Papers and Discussions on Experiments with Steel. Reprinted from various sources.
15. Papers and Discussions on Ships, Guns and Armor. Reprinted from various sources.
16. Papers and Discussions on Engines, Boilers and Torpedo Boats. Reprinted from the "Transactions of the Institution of Naval Architects."
17. The Magnetism of Iron and Steel Ships. An explanation of the various ways in which it affects the Compass. By Lt.-Com. T. A. Lyons, U. S. N.
18. Training of Enlisted Men: Three Papers reprinted from the "Journal of the Royal United Service Institution."

From Relfe Brothers, 6 Charter-House Buildings, London, E. C.:

A New English Grammar; My First French Course; My First French Phrase-Book. By A. Grover, LL. D.

First Principles of Euclid; First Principles of French History; First Principles of English History; First Principles of English Grammar. By T. S. Taylor.

First Year of Scientific Knowledge. By Paul Bert.

A Latin Book for Beginners. By C. H. Gibson.

English Spelling as it is.

Relfe Brothers' Model Reading Books, Nos. 3, 4, 5, 6.

Cassell's Magazine of Art for March.

STATISTICS OF HYDRAULIC WORKS AND HYDROLOGY OF ENGLAND, CANADA, EGYPT AND INDIA. By LOUIS D'A. JACKSON. London: W. Thacker & Co.

This work is an enlargement of the second part of the "Hydraulic Manual and Statistics" by the same author. The additions are extended, obtained partly by the author's own work and partly from other reports and records.

The regions are described separately and in the order given in the title. In Great Britain, the river basins, canals, storage works, sewage irrigation, irrigated crops and analysis of water are treated in turn.

Of Canada, only river basins, canals, navigations, geology and meterology are presented.

Of Egypt, the hydrology of the Nile, the irrigation, irrigated crops and analysis of the water occupy most of the space.

Of India and Ceylon, the rivers, canals and tanks or storage works are of chief importance. The history of the progress of these works is full of interest.

The work will prove to be a valuable guide to engineers who are charged with similar works in other countries.

The details of the engineering features are regarded as subordinate to the economic and commercial phases of the improvements, so the statistics relate to expenditures for cost and values received.

The book is well printed but is without illustrations of any kind.

THE THEORY OF STRESSES IN GIRDERS AND SIMILAR STRUCTURES, WITH PRACTICAL OBSERVATIONS ON THE STRENGTH AND OTHER PROPERTIES OF MATERIALS. By BINDON B. STONEY, LL. D., F. R. S., Member of the Institution of Civil Engineers. Price, $12.50. New York: D. Van Nostrand.

The new edition of this well-known standard work exhibits several new and important features. The general principles of graphic statics are introduced early in the treatise, and graphic solutions form a conspicuous feature of the book.

Additions have also been made to the subjects of oscillating stresses, working loads, wind pressure, steel, pillars and riveting.

Full advantage has been taken of the results of tests of materials made known since the previous edition was written The total result is an octavo volume of 777 pages, with 143 illustrations and five folding plates.

The following are the headings of the various chapters: Introductory; Flanged Girders with Braced or Thin Continuous Webs; Transverse Stresses; Girders of Various Sections; Braced Girders with Parallel Flanges and Webs, formed of Isosceles Bracing; Girders with Parallel Flanges, connected by Vertical and Diagonal Bracing; Braced Girders with Oblique or Curved Flanges; Deflection; Continuous Girders; Quantity of Material on Braced Girders; Angle of Economy; Torsion; Strength of Hollow Cylinders and Spheres; Tensile Strength of Materials; Crushing Strength of Materials; Pillars; Shearing Stress; Elasticity and Set; Temperature; Web; Flanges; Wind Pressure and Cross Bracing; Cross Girders and Bridge Flooring; Counterbracing; Deflection and Camber; Depth of Girders and Arches; Working Stress and Working Load; Fastenings and Connections; Estimation of Girder Work; Appendix.

DYNAMO-ELECTRIC MACHINERY.—The following letter to the editor of the *Electrician* (American) will appear in the March issue of that journal:

To the Editor of the Electrician:

SIR:—In the second edition of Prof. S. P. Thompson's work upon "Dynamo-Electric Machinery," which has recently appeared, I notice that the author has reprinted the preface which appeared to his first edition. This original preface contained certain statements which, at the time, I passed over in silence, because I thought that the majority of the readers of his book in this country would readily see the injustice of the reflections contained therein. My reasons for thinking so were, that inasmuch as the statements there made were evidently penned in an unfriendly spirit, and as they seemed to give an unjust impression regarding the dealing of American publishers with English authors, they were at the same time accompanied with a positive declaration that the lectures complained of as reprinted by me, were reprinted as well in the *Electrician* (English), the *English Mechanic*, and other technical journals, and were translated into French; and as Professor Thompson did not intimate that he was the recipient of a check from these journals, or from the French publisher, I imagined that Professor Thompson's readers, in this country, at least, would not judge me harshly for not doing what no one else who had used his lectures had done, or which even he (Prof. Thompson) would seem to have expected them to do.

I think, perhaps, now that this second edition of his extended work has appeared, containing this original preface, that a statement of the case may properly be made.

In 1883 there appeared in the *Journal of the Society of Arts* a series of papers, being certain lectures delivered by Professor Thompson. As is the custom with the editor of my Magazine, when any really valuable contributions appear in that journal, he reprinted them, and they may be found in the ENGINEERING MAGAZINE for March, April, and May, 1883, duly credited to the *Journal of the Society of Arts.* Subsequently they were printed in a collected form in my "Science Series," after having been submitted to the able editorship of Mr. F. L. Pope. In this form I printed 1,000 copies, and after paying the cost of the cuts, paper, printing and binding, when all are sold, at the small retail price of 50 cents, at which they were placed, there will be but a very inadequate margin of profit on the venture. The author seems to ignore the fact that the magazine in which his lectures appeared in this country, and which magazine is conducted at considerable annual loss to the publisher, first gave publicity to them here, and which the subsequent reprinting of them in the "Science Series" helped to enhance, and to this fact, let me assure the author, is due very much of his reputation, as well as of the demand for his larger work in the United States. D. Van Nostrand.

MISCELLANEOUS.

Mechanical Uses for Natural Gas.—At many of the wells near Pittsburgh the natural gas issues with an initial pressure of 200 lbs. to the square inch, or even more, and before it can be used as fuel or illuminant, must have this pressure considerably reduced. where the pipe lines are of any great length, the friction of the gas against the sides and angles is sufficient to accomplish the purpose; but where the fuel is used directly from the well, or where the transit is but short, mechanical devices become necessary. It is now proposed, however, to make use of the force thus stored up in the compressed gas, instead of wasting it, as heretofore, or making provision for its dispersion. One plan suggested utilizes the pressure for blowing blast furnaces, thus dispensing with the enormous engines now employed for that purpose. Sufficient air would, of course, have to be introduced along with the gas to furnish the oxygen necessary for its combustion, and for so much of the solid fuel in the furnace charge as was not oxidized in the reduction of the ore or combined in the resulting pig iron. Should this plan prove practicable, it would also lessen to a great extent, the amount of solid fuel in the burden, and would be a preliminary step in the solution of the problem of a gas blast furnace. Another proposition is to make use of the gas in working engines similar to those using compressed air. The gas, after giving up its stored mechanical energy, would be equally available for the production of light or heat, and its entire power would be utilized. If the supply of natural gas proves at all permanent, it promises to become daily more valuable. Mr. Andrew Carnegie, in his description of the Pittsburgh field, mentions one well, in the Murraysville district, which yields 30,000,000 cubic feet of gas in twenty-four hours. Although this is exceptional, there are many which have a daily output of half this amount, and within a radius of from fifteen to twenty miles around Pittsburgh there are four distinct gas-producing districts. The only question to our mind is whether this supply and pressure will be permanent.

Transmission of Drawings by Signal.—Lieutenant A. Glen, of the Inns of Court Volunteers, read a paper on this subject at the Royal United Service Institution on January 15th. The author, in introducing his subject, said he had been induced to take up the question of army signaling at the suggestion of Colonel Bonham, district signal officer, who expressed the opinion that it was a subject that might well be taken up by volunteers with advantage to the regular army. At the Easter review in 1884, Lieutenant Glen, being in charge of the Inns of Court signaling party, put his scheme in practice, and was able to test its merits and discover its defects, most of which had since been remedied. Lieutenant Glen explained that the object of the system is that one person who has the means of communicating with another by telegraph, heliograph, lamp, flag, or other mode of signaling, may enable the recipient of the signals to make a facsimile of any drawing which may be in the hands of the sender. The drawing may be of any kind, from a rough sketch or plan to a photographic likeness or a chromo-lithograph. The accuracy with which the drawing is transmitted may be increased to any extent that the sender may think fit, while the scale on which the facsimile is drawn is at the discretion of the recipient. The system is based upon the representation of the position of a point by its Cartesian co-ordinates approximately. Polar co-ordinates might be used in almost the same manner, but it would then be found that the accuracy with which the position of a point was represented increased as its distance from the pole diminished, and this peculiarity would be advantageous in signaling the diagrams of a rifle match. Having described the working of his system with the aid of a number of diagrams, Lieutenant Glen gave interesting details of several experiments that had been made with a view to prove the accuracy by which a drawing might be signaled. One of these experiments was the sending by message a likeness of Colonel Bulwer, Q. C., M. P., which was reproduced by the recipient on a larger scale, and recognized upon its completion by those present as a good portrait. In the discussion that followed, Colonel Melville, R. E., briefly described a system which he had patented, having the same object as that invented by Lieutenant Glen, and Mr. H. L. Pilkington adverted to the valuable aid that might be rendered to an army in the field by means of such processes. The Chairman (Colonel Moncrieff), in moving a vote of thanks to the lecturer, observed that he had managed to invest the technical details of his subject with considerable interest, and had made many valuable suggestions, which showed with what assiduity he had studied the question of army signaling.

The Use and Abuse of the Indicator.—At the meeting of the Manchester Association of Engineers, held on January 23, Mr. W. H. Bailey in the chair, an interesting paper on "The Use and Abuse of the Steam-Engine Indicator" was read by Mr. James Hartley. In the course of his paper, Mr. Hartley pointed out that, although the principal use of the indicator was to exhibit the behavior of the steam in the cylinder of an engine, this was by no means the only purpose to which it could be advantageously applied. In fact it afforded the sole means of exhibiting and recording the changes of pressure that took place in any chamber in which an elastic fluid was confined. It was well known that the action of steam-engines working expansively, especially with small pipes and valves, produced pulsations in the boiler sometimes of a dangerous character, and the extent of these pulsations could only be shown by the application of the indicator. The indicator was also useful to apply on the delivery pipes of certain classes of pumps, to ascertain whether or not the pumps were working satisfactorily, which, in a great many cases was questionable. If engineers and engine tenters would only devote a little more time to the study of the use of the indicator, and the diagrams taken by it, there would be very few of the wasteful engines that were often referred to, and we should be able to obtain the maximum amount of power for the minimum amount of fuel consumed. He wished, however, to point out emphatically that reliable diagrams could not be obtained unless the following conditions were complied with: 1. A good indicator in thorough working order. 2. A careful and competent operator. 3. Suitable tap placed at each end of the cylinder, not loop pipes, with a three-way tap in the center, as, however convenient these may be, they were not satisfactory, as the diagrams must certainly be somewhat inaccurate on account of leakage at times, also from the fact that the steam had a longer distance to travel before acting on the piston of the indicator, especially in engines with long strokes. 4. A good, sharp, metallic point, and good paper; and, lastly, a correct method of giving motion to the barrel of the indicator. If all these conditions were not complied with, unsatisfactory and unreliable diagrams would be the result. The president said they had had a very practical and useful paper. Progress in engineering was very much dependent upon the delicacy and accuracy of the instruments they had to use, and it was in the knowledge of differences that scientific men showed their ability. Mr. Lavington Fletcher said the indicator was a most useful instrument, but might be abused, and the loop pipe was a great trap, and very deceptive. The indicator would not always tell them the amount of steam passing through the engine. Very often, when a complete test was made, a discrepancy of 30 per cent. was discovered; and if any member of that association could invent some kind of meter that they could apply to the hot overflow of an engine, it would be invaluable. They must not be content with the indicator as it is, and he hoped some one would try the testing of the heat that passed out of the engine. Mr. Lewis said, to his mind, the indicator was by no means perfect, and no system of levers could be reliable. He thought some instrument might be devised for communicating the motion of the engine direct to the indicator. Mr. Taylor said that, for very high speed engines, it was a question whether anything in the present shape of indicators was altogether reliable. The primary use of the indicator was that it should record the exact pressure of the steam at any particular part of the cylinder. The usual vote of thanks closed the proceedings.

PROFESSOR CORFIELD, the medical officer of health of St. George's, Hanover square, has presented to the governing body of the district—which includes Belgravia, Mayfair, and the central parish of St. George's—an interesting account of matters relating to health in that part of London. In the completed twelve months under notice, while the death rate of London as a whole stood at 20.3, and of twenty-eight large towns in England at 21.6 per 1,000 of population, the rate of all St. George's stood at the low figure of 16.30. The low death rate of St. George's is not only in strong contrast with the rates in other parts of London, but also with some of the large English, Scotch and Irish towns. Preston, in Lancashire, has the largest death rate of the English towns, standing at 27.3 per 1,000 of the population, and is closely run by Manchester, with 26.4, which is again closely run by Liverpool, with 25.2. Glasgow had a death rate in 1884 of 26.9, and Dublin 27.5. There were only five towns in England which had a lower death rate than St. George's.

THE Minot's Ledge lighthouse near Boston, U. S., harbor, is a solid granite structure 200 ft. high, and in a recent gale was severely tried. The keeper of the lighthouse says: "The gale increased constantly, and on Wednesday night we could not sleep on account of the noise. Everything placed against the walls rattled and the thunder of the sea was terrific. Thursday morning I was in the watch-room, just below the lantern, when a sea struck, breaking heavily against the solid granite wall, and dashed its spray and foam 40 ft. to 50 ft. above the pinnacle. The spray from nearly every wave broke over the tower, but none seemed to have a force equal to this. We thought it the heaviest gale at that time the lighthouse had ever experienced, but still the winds went on increasing and the shocks were of greater power. At 2.30 o'clock, and just about high tide, another tremendous wave struck it, still heavier than the one in the night, starting the paint from between the cracks in the ceiling of the watch-room and moving about in all directions. This was the last great effort to beat down the structure, and soon after the gale began to abate."

THE TALLEST CHIMNEY IN THE WORLD.—In the summer of 1884 a new chimney stack was commenced by the Mechernich Lead-Mining Company, which had reached a height of 23 meters when the works were discontinued on account of the autumn storms commencing, On the 14th of April, 1885, the building was resumed, and on the 19th of September following, the total height of 134.6 meters was reached. The leading dimensions are as follows: The foundation, in dressed stone masonry, is 11 meters square, and 3.5 meters high. The base, a cube of 10 meters, and the octagonal plinth of the shaft, are built of annular-kiln bricks. The shaft, of circular form, in radial bricks, is 121.1 meters high, 7.5 meters outside, and 3.5 meters inside diameter at the base, and 3.5 meters outside and 3 meters inside diameter at the top. The height, of 134.6 meters (441.6 ft.), is 2.1 meters (6.9 ft.) more than that of Tennant's chimney, at St. Rollox, which is given as 132.5 meters (434.7 ft.).

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TREATISE ON THE THEORY OF THE CONSTRUCTION OF HELICOIDAL OBLIQUE ARCHES.*

By JOHN L. CULLEY.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

PREFACE.

I have attempted in this treatise to attain two results:

First.—To supply our American engineering literature with a short, clear treatment of the construction of Helicoidal Oblique Arches; and,

Second.—To render simple all problems connected with their theory or construction. I especially hope that I may make the second plain to all who shall read these pages.

Long since I have been satisfied that much of the confusion and misunderstanding arising from the attempts to understand this subject, have arisen from the fact that authors have failed, either to state the fundamental principle, or to keep it constantly before the student's mind. Hence the general opinion has arisen, that helicoidal arches are of the most intricate construction, and too often their consideration has been abandoned with disgust.

The conception of a single principle will clear away all this misunderstanding. It is that of the process of the generation of helicoidal surfaces. It is a simple one, and, if constantly kept in mind, will render all other problems equally simple. No engineer's education is complete without a thorough knowledge of this subject. If the simple propositions of Chapter I. are mastered, there will be no trouble with the remainder of the treatise.

CHAPTER I.

ELEMENTARY PRINCIPLES.

1. A *helix* is a cylindrical curve that in passing over equal portions of the circumference of the cylinder, it travels over equal portions of the length of the cylinder.

2. Thus, in Fig. 1, A B C is the elevation of the semi-cylinder, A C D E, whose diameter is A C, and length is A E. Let A E also be the cylindrical length of the semi-helix, A D, whose elevation is A B C.

Divide A E and the circumference, A B C, each into the same number of parts of equal length, as shown in Fig. 1. Through the points, 1, 2, 3, &c., of A E draw lines parallel to A C, and through the corresponding points, 1′, 2,′ 3′, &c., of A B C, draw lines parallel to A E. The intersections, 1″, 2″, 3″, are points, in the plan, of the semi-helix, A D.

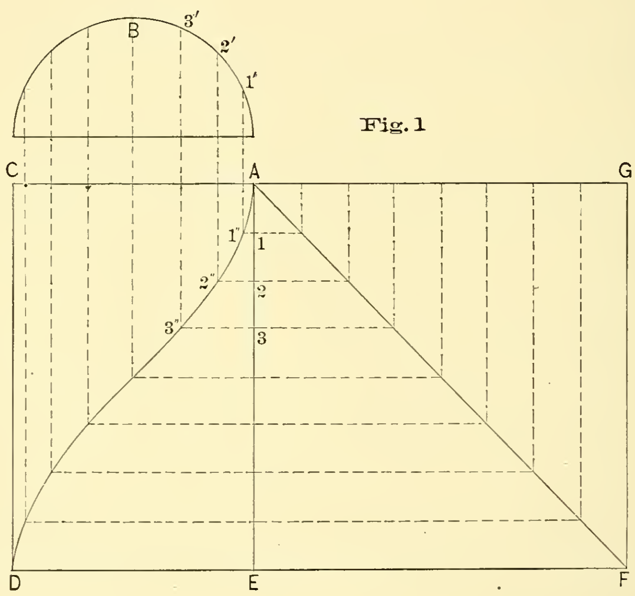
Any number of points may thus be determined, and the curve of the semi-helix readily located, or drawn in the plan, Or, when the relation of the cylindrical length to the semi-circumference is constant, we can readily determine the equation of the curve, A D.

3. If the cylindrical surface, A C D E, be straightened out into a plane surface, its width will evidently be equal to the semi-circumference, A B C, and its length will be equal to A E, whilst the semi-helix, by construction, would become a straight line on this surface. Therefore, in Fig. 1 draw A G equal to the semi-circumference, A B C, perpendicular to A E, and complete the rectangle, A E F G. This rectangle is called the *development* of the semi-cylindrical surface, A C D E, since it is its equivalent in plane surface. If we regard A C D E the inner surface or *soffit* of a right arch, A E F G is the development of the intrados, and the straight line, A F, is the development of the intradosal semi-helix, A D.

4. From this we can determine the location in the plan of a semi-helix I J normal to A D at L (Fig. 2). Its development will evidently be also a straight line perpendicular to A F. Through L draw L M parallel to A G, intersecting A F at M, I M H drawn through M perpendicular to A F, is the development of the semi-helix normal to A D at L. Draw H J parallel to A G, then J and I will be the extremities of the normal semi-helix in plan, whose cylindrical length is I K, and elevation is A B C, whence we can determine the J L I in the same manner as A L D was determined. and as here shown.

5. In Fig. 3 H I J is the elevation, and H J K L the plan of the extrados or outer surface of a right arch of the depth I B, whose extradosal development is H L M N, wherein H N equal to the semi-circumference H I J is drawn perpendicular to H L, and L M and M N are respectively drawn parallel to H N and to H L.

The extradosal and intradosal developments are both made from the axis X X for the convenience of comparison of these surplan of the semi-extradosal helix H I J, faces and their lines. Here H P K is the whose cylindrical length H L is equal to H E of the semi-intradosal helix A P D. The curve H P K is determined from H L and H I J in the same manner as was A P D from A E and A B C. The straight line H O M is the development of H P K.



By construction P and O, the respective points of intersection of the curves H P K and A P D, and of the straight lines H O M and A O F are both on the line X X—X′X′, *i. e.* in plan and in development.

6. The surface included between the curves H P K and A P D is called the arch helicoidal surface, or arch helicoid, and a careful examination of Fig. 3 will

elucidate to us the fundamental principle of helicoidal arch analyses and construction. This fundamental principle is that of the process of the generation of this helicoidal warped surface.

7. All lines $1\,a-1'a'$, $2\,b-2'b'$, &c., are evidently elements of, and the only straight lines lying entirely within this warped surface, $1\,a$, $2\,b$, &c., are the actual lengths of $1\,a-1'a'$ of $2\,b-2'b'$, &c., since $1'a'$, $2'b'$, &c., produced are normal to the axis X X, or parallel to the right section of the arch. They are each equal to I B the depth of the arch as they are the portions of the radii $x\,1\,a : x\,2\,b$, &c., included between A B C and H I J.

8. Whence, when the right sections of the intrados and the extrados of an arch are circular arcs, we derive the following fundamental principle:

First. *A helicoidal surface is generated by a right line perpendicular to and moving on the axis as one directrix and on a helix as the other directrix, and the arch helicoid is that part of this surface generated by that portion of the generating line, equal to the depth of the arch, and included between the intrados and the extrados. The said generator of the arch helicoid is at all times perpendicular to the intradosal and extradosal helices of such helicoid.*

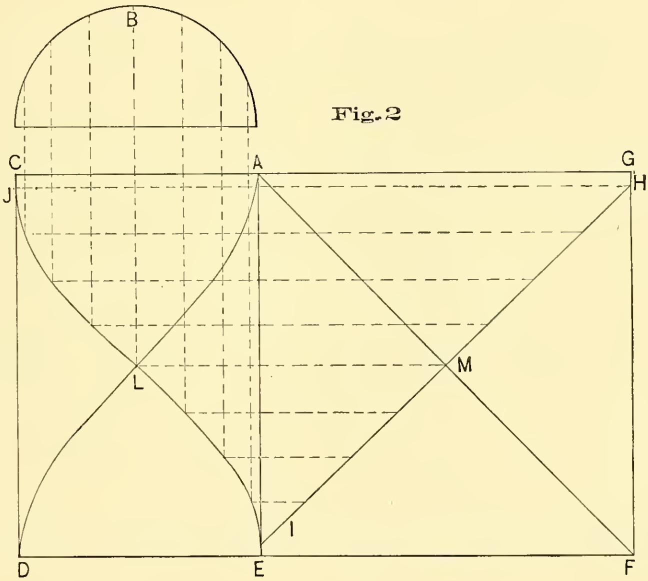


Fig. 2

Again the radii $x\,1\,a$, $x\,2\,b$, &c., at their points of contact in the intrados and in extrados, are perpendicular to these surfaces, and are perpendicular to all lines within these surfaces passing through these points of contact, and are therefore perpendicular to the helices passing through these points. In other words, any radius $x\,1\,a$ or $x\,2\,b$ drawn from the axis XX to either intradosal or extradosal helix, is at the point of contact with the helix perpendicular to it. From this it follows that the elements $1\,a-1'a'$; $2b-2'b'$, &c., are perpendicular, at the same time, to both the intradosal and extradosal helices A P D and H P K.

And as a corollary,

The intradosal and extradosal helices of an arch helicoid are parallel spiral curves whose perpendicular distances apart equal the depth of the arch.

9. These deductions are the essence of all problems connected with this subject. Nor should any one pursue it further without a thorough mastery of the principles here stated. A full understanding

of the process of the generation of helicoidal surfaces is of the first importance, and such a conception will render all further consideration of the elements of these warped surfaces clear and simple.

Chapter II.

HELICOIDAL CURVES AND TEMPLETS—TWIST RULES.

10. In the plan (Fig. 4) of the intradosal helix, make P S′ equal to P R′, and join R′ and S′ by a straight line, R′ S′, R′ S′ will, by construction, pass through P, R S will be its elevation. If, then, we lay off R″ S″ equal to and parallel to R′ S′, we can construct on it the curve of the intersection of a right vertical plane, R′ P S′, with the intrados, A C D E. It will be evident, by reference to the elevation, A B C, that the middle ordinate of R″ S″ at X will be X 4 equal to X B in elevation. Again, if at U and T in the elevation we draw perpendiculars to R S, these perpendiculars will respectively equal the ordinates V 3 and W 5 of R″ S″ at V and W. In this manner may be obtained any number of points, 3, 4, 5, &c., and the curve, S″, 3, 4, 5, &c., R″ constructed, which will be the curve of the intersection of the vertical plane, R′ S′, with the intrados, A C D E.

11. The corresponding extradosal elliptic curve, 6 7 8, may be similarly constructed, or both it and the intradosal curves may be determined for the equation of these elipses.

12. Let R″ R′ S′ S″ (Fig. 5) be the plan and S″, 3 4 5 R″ the elevation of a piece of timber of any thickness, R″ R′. On R″ R′ S′ S″ produce R′ P S′ of the plan of the helix in Fig. 4 at any convenient distance from, and parallel to, R′ P S′ draw the dotted line here shown. The space between R′ P S′ and the dotted parallel line will be the plan, and S″ 3 4 5 R″ the elevation of a templet of the intradosal helix, or the soffit cousing joint, R B S—R′ P S′.

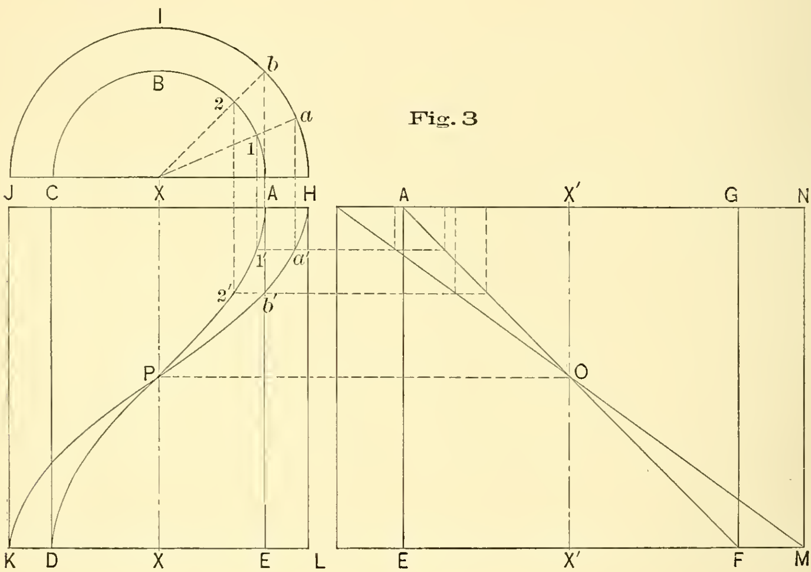


Fig. 3

In like manner the templet of the extradosal helix may be constructed. When any considerable portion of a helix is to be treated at one time this is the true way to construct the coursing joint templets.

TWIST RULES.

13. Let Fig. 6 be an enlarged drawing of the plan and development of the helices, A P D and H P K, between the point, P O, and the element, 1′ a' (Fig. 3). It will be observed that the point, P, is the the plan of a vertical element of the arch helicoid, or the element at P is perpendicular to the horizontal plane. The element P and the point, 1′, of the intra-

dosal helix, locate the vertical plane passing through P and 1′, whose trace on the horizontal plane is P 1′3′. Then the line, a'3′, drawn from a' in the extradosal helix perpendicular to the vertical plane, P′ 1′ 3, is the measure of the warp of the arch helicoid at 1′ a'—1 a' from the plane, P 1′ 3′, for the given depth, I B, of the arch.

14. 1′ a' is, by construction, equal to I B and a' 3′ being perpendicular to the vertical plane, is perpendicular to any line within the vertical plane passing

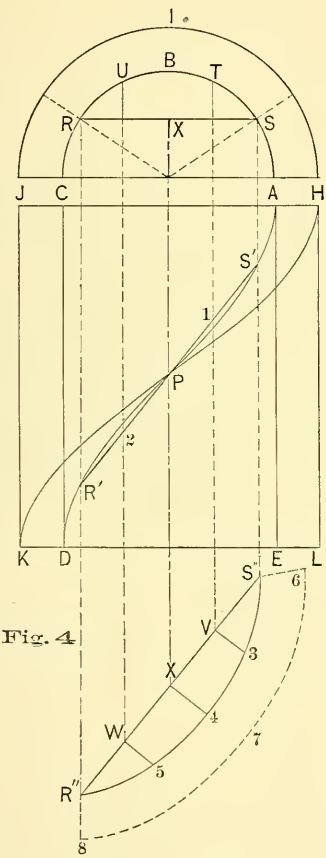


Fig. 4

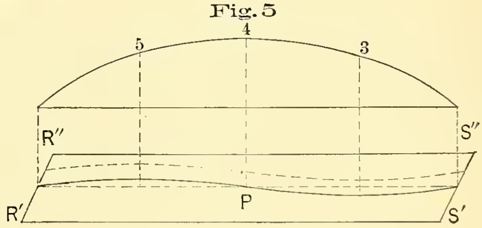
through its foot, 3′. Consequently a' 3′ is perpendicular to the line whose plan is 1′ 3′.

Therefore on the straight line, 4 5 (Fig. 7) erect the perpendicular, 5 6, equal to a'3′, and with 6 as a center, intersect 4 5 at 4 with an arch whose radius, 4 6, equals I B, the depth of the arch. 4 5 6 is the actual size of the wedge, 1′ 3′ a', in plan, that is perpendicular to the vertical plane, P 1′ 3′, and that supports the plane above the helicoid, P 1′ a' at 1′ a'. It should be noticed that 4 5 is the actual length of the line, 1′ 3′, in the plan or trace of the vertical plane.

15. To determine the warp of any element, 2′ b', from b' and from 2′ draw the perpendiculars, b' 7 and 2′ 8 to P 1′ 3′. Then on any line, 9 10, erect a perpendicular, 10 11, equal to b' 7, and lay of 10 13, equal to 2′ 8, and through 13 draw 12 13 parallel to 9 10. Then, with 11 as a center, intersect 12 13 at 12 with an arc of the radius, 11 12, equal to I B, and draw 9 12 parallel to 10 11. 9 10 11 12 will be the actual size of the truncated wedge shown in plan at 2′ b' 7 8, that is perpendicular to the vertical plane through P and 1′, and that supports this plane above the helicoid at 2′ b—2 b.

In same manner the warp of any element of the helicoid from the vertical plane, P 1′ 3′, may be obtained.

Fig. 5



16. The figures 4 5 6; 9 10 11 12, and a straight line, 14 15, equal to I B, are templets of the helicoid respectively at 1′ a'—1 a : 2′ b'—2 b, and at P—O, and in applying them care should be exercised that the lines 4 6 and 11 12 are applied to the helicoid with the points 4 and 12 exactly at 1′—1 and at 2′—2, and with the points 6 and 11 exactly at a'—a and at b'—b. The lines, 4 5 and 9 10 are, of course, to be brought exactly into the plane, P′ 1′ 3′, while the straight line, 14 15, will be applied at the intersection of the plane P 1′ 3′, and the helicoid at P—O. In practice, however, a straight line, 14 15, cannot be used. Therefore, draw 16 17 parallel to 14 15 = 15 16 and increase the depths of 4 5 6 and of 9 10 11 12 each a distance equal to 14 17 to the dotted line shown.

Then 16 17 and the dotted lines, 4 5 and 9 10, will be in a plane parallel to the plane, P 1′ 3′, and these *parallel* and *twist rules* should, when applied, be always perpendicular to this parallel plane that they may ever be perpendicular to the first plane, P 1′ 3′.

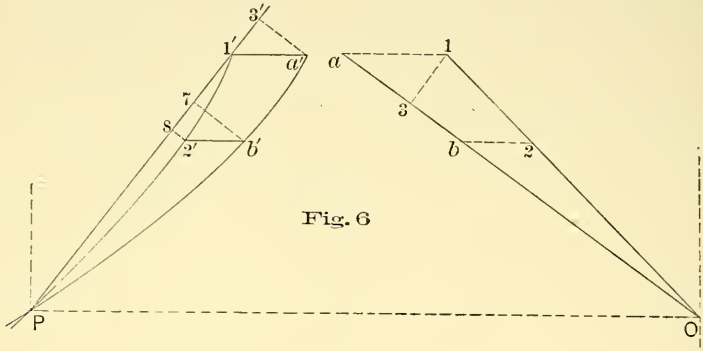


Fig. 6

The parallel and twist rules are all known as twist rules, as they are the templets by which the warp of the coursing beds are worked.

17. Fig. 8 is a perspective view showing the manner of applying the twist and parallel rules of Fig. 7. 15 11 6, is the extradosal helix whose exact length and

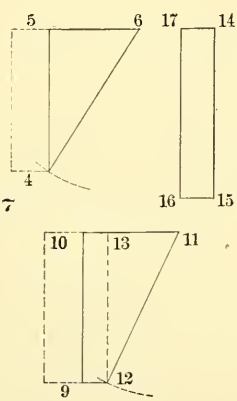
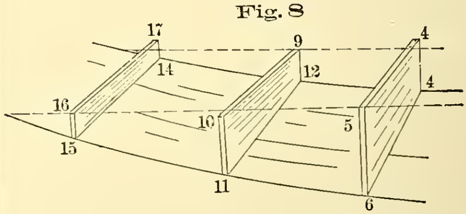


Fig. 7

that of its parts, 15 11 and 11 6, are taken from the development (Fig. 6), and are respectively equal to O *a*, O *b* and *b a*. 14 12 4 is the intradosal helix equal to 0, 1, and its parts 14, 12 and 12, 4 are equal to 02 and 21 (Fig. 6). The parallel and twist rules are of the same size and characteristics as in Fig. 7. Their upper edges 16 17, 9 10, and 4 5 lie in and coincide with the plane 4 5 16 17, to which these rules are perpendicular. The corners of the rules 6 11 and 15 are in the extradosal helix 6 11 15, while the corners 4 12 and 14 are in the intradosal. It will also be noticed that since the lower edges of these rules coincide with elements of the helicoid, they are and should be normal to the two helices of the helicoid.

18. We have here used in Fig. 8 three rules simply for the convenience of illustration. In practice, many may be used. Sometimes a parallel rule and a single twist rule will be all that are needed, and in fact this will generally be the case. The number of twist rules to be used depends upon the length and warp of the

Fig. 8



voussoir treated. However, enough of these should always be used to exactly determine the warped helicoids.

19. This method of determining the warped helicoids will overcome Professor Hyde's objection to the ordinary method of determining them, referred to in his book, "Skew Arches," pp. 11 and 12.

20. John Watson Buck in his treatise on this subject, "Essay on Oblique Bridges," pp. 13 and 14, presumes to determine the warp of the helicoids in the following manner: Let P 1′ *a*′ and

O 1 a (Fig. 9) be the plan and development a helicoid. From 1 in the development, draw 1 3′ perpendicular to O a. It is there stated that 1 3′ is the warp of the element 1′a' from the plane P 1′ 3′. It has already been proven equal to a' 3′. Therefore a' 3′ would have to be equal to 1 3′. But by construction they are not equal. Hence it is that Buck's rule is not strictly true. But inasmuch as the length of the voussoirs are nearly always small in comparison to the whole length of the helix, this rule, though not theoretically true, is practically correct; for at the points P and O the curved lines 1′ 2′ P and a' b' P, and the straight lines 1 2 0 and a b 0 make the same included angles.

But if warped helicoids of any magnitude are to be worked at one time, it would not be safe to use Buck's rule. The rule we have given is true for any length of the helicoid, and as easily obtained and applied as Buck's, and there is no reason why it should not be always used.

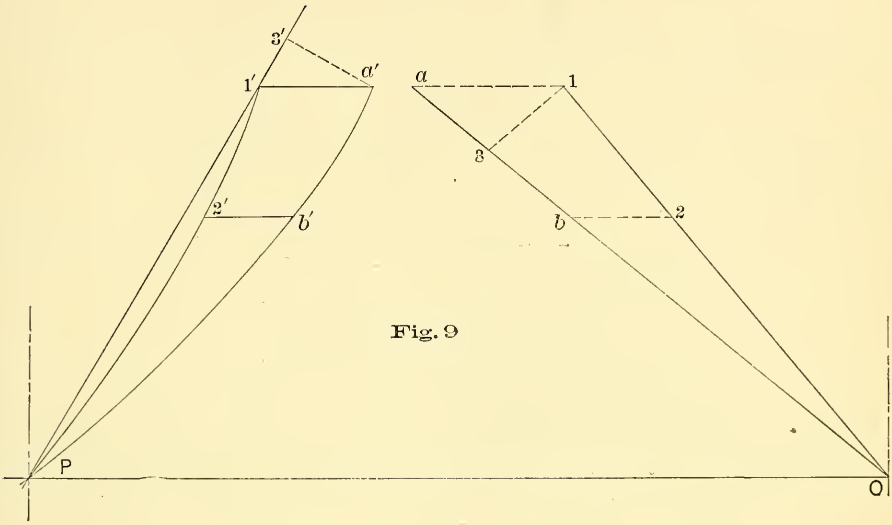


Fig. 9

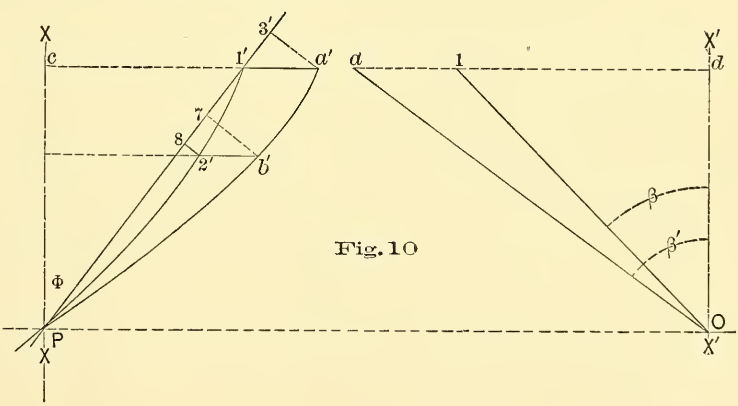


Fig. 10

21. Produce the lines 1′ a' and 1 a (Fig, 10) to c and d in XX and X′X′

Let the β be *angle of the intrados*, 1 O d'; β' be the *angle of the extrados* a O d' (Fig. 10); Φ equal the angle 1′ P c

=angle $3'a'1'$ by construction; r the radius of the intrados and r' the radius of the extrados, $\frac{1\,d}{\pi r}=\frac{a\,d}{\pi r'}$.

Then

$$Pc=Od=O\,1 \text{ cosin } \beta=Oa \text{ cosin } \beta' \quad (1)$$

$$1\,d=Od \tan. \beta \quad . \quad . \quad (2)$$

and $$a\,d=Od \tan. \beta' \quad . \quad (3)$$

$$c\,1'=r \sin.\left(\frac{1\,d}{\pi r}\,.\,180^\circ\right) \quad . \quad . \quad (4)$$

$$ca'=r' \sin.\left(\frac{a\,d}{\pi r'}\,.\,180^\circ\right) \quad . \quad (5)$$

Whence we obtain

$$1'a=c\,a'-c1, \text{ and tang. } \Phi=\frac{c\,1'}{P\,c} \,. \quad (6)$$

$$\therefore \quad 3'a'=1'a \sin. \Phi \quad . \quad (7)$$

In like manner any warp distances b' 7 and $2'$ 8 may be obtained.

KUTTER'S FORMULA.

By P. J. FLYNN, Mem. Tech. Soc.

Transactions of the Technical Society of the Pacific Coast.

Kutter's formula for feet measures is—

$$V=c\sqrt{r\,s} \quad . \quad . \quad . \quad . \quad (1)$$

where

$$C=\frac{41.6+\frac{1.811}{n}+\frac{.00281}{s}}{1+\left(41.6+\frac{.00281}{s}\right)\frac{n}{\sqrt{r}}} \quad . \quad (2)$$

In this formula and in what follows:

V=velocity in feet per second.

C=coefficient of mean velocity.

S=fall of water surface (h), in any any distance (l), divided by that distance$=\frac{h}{l}$=sine of slope.

R=hydraulic mean depth in feet=area of cross-section of pipe or conduit or channel in square feet divided by its wetted perimeter in lineal feet.

D=diameter of pipe or conduit.

N=the natural coefficient, the value of which depends on the nature and condition of the bed of the channel through which the water flows, or, in other words, its degree of roughness.

In that admirable and useful work, "Molesworth's Pocket Book of Engineering Formulæ, a modified form of Kutter's formula for pipe discharge is given, in which the value of

$$C=\frac{181+\frac{.00281}{s}}{1+.026\left(41.6+\frac{.00218}{s}\right)} \quad . \quad (3)$$

For facility of reference I will call this equation Molesworth's Kutter (3), and equation (2) Kutter's formula (2). No mention is made by Molesworth of the value of n, that is, as to whether the formula is intended to apply to pipes having a *rough* or a *smooth* inner surface. An investigation will, however, show that his formula is accurately applicable to *only one* diameter, that is, to a diameter of one foot, and with the value of n=.013.

The value of the term $\frac{n}{\sqrt{r}}$ in formula (2) is given by Molesworth in formula (3) as a *constant* quantity, whereas, in fact it is a *variable* quantity, its value, with the same value of n, changing with every change in the hydraulic mean radius or diameter of pipe.

Now, assuming the value of n taken by Molesworth to be=.013, and substituting this value for n in formula (2), we have

$$C=\frac{41.6+\frac{1.811}{.013}+\frac{.00281}{s}}{1+\left(41.6+\frac{.00281}{s}\right)\frac{.013}{\sqrt{r}}}$$

and

$$\therefore\ C = \frac{181 + \frac{.00281}{s}}{1 + \left(41.6 + \frac{.00281}{s}\right)\frac{.013}{\sqrt{r}}} \quad . \quad (4)$$

but by Molesworth's Kutter (3)

$$\frac{.013}{\sqrt{r}} = .026$$

$$\therefore\ \sqrt{r} = 0.5$$

$$r = .25$$

$$\text{and } d = 1$$

If we substitute in formula (4) for $\sqrt{r}$ its value 0.5, we have—

$$C = \frac{181 + \frac{.00281}{s}}{1 + .026\left(41.6 + \frac{.00281}{s}\right)}$$

which is Molesworth's Kutter.

It is, therefore, apparent that no matter what the value of n may be, Molesworth's Kutter (3) does not give the same results as Kutter's formula, as it gives a *constant* coefficient of velocity, c, for all diameters having the same slope and the same value of n.

Kutter's formula (2) has certan peculiarities which are wanting in Molesworth's Kutter, and an investigation will show that Molesworth's Kutter differs materially from Kutter's formula, and that its application, except to one diameter, is sure to lead to serious error. I will briefly explain. In what follows $n = .013$.

1, By Kutter's formula (2) the value of c, or the velocity changes with every changes with every change in the value of r, s or n, and with the *same slope* and the same value of n, the value of c increases with the increase of r, that is, with the increase of diameter. It is on this variability of its coefficient to suit the different changes of slope, diameter and lining of channel that the accuracy of Kutter's formula depends.

By Molesworth's Kutter a change in the diameter, other things remaining the same, does not affect the value of c. With the same slope the value of c is *constant* for all diameters.

As an instance, with a slope of 1 in 1,000—

	6 Inches Diameter C=	20 Feet Diameter C=
By Kutter's formula (2)...	69.5	146.0
By Molesworth's Kutter (3)	85.3	85.3

It will thus be seen that the value of c by Kutter's formula (2) when $s = .001$, has a large range from 69.5 to 146, showing an increase of 111 per cent. from a diameter of 6 inches to a diameter of 20 feet. In this case, Molesworth's Kutter gives a *constant* coefficient of 85.3, and this coefficient applies to all diameters with a slope of 1 in 1,000.

It will be further found that Molesworth's formula gives the value of c, and, therefore, the value of the velocity and discharge, too high for diameters less than one foot, and too low for diameters above one foot, and the more the diameter differs from one foot the greater is the error. In these respects it follows the error of the old formulæ.

2. According to Kutter's formula (2) the value of c increases with the increase of slope for all diameters whose hydraulic mean depth is less than 3.281 feet—one meter—and with a hydraulic mean depth greater than 3.281 feet, an increase of slope gives a diminution in the value of c.

The small table herewith given shows this.

	12 Feet Diameter.		20 Feet Diameter.	
	1 in 1,000.	1 in 40.	1 in 1,000	1 in 40.
Molesworth's Kutter, c=...............	85.3	86.9	85.3	86.9
Kutter's formula, c=..................	137.7	137.9	146.0	145.7

It will be seen that by Kutter's formula, when $r=3$ feet, that is, less than 3.281 feet, an increase in the slope from 1 in 1,000 to 1 in 40 causes a slight increase in the coefficient, but when r is 5 feet, that is, more than 3.281 feet, the same increase in the slope causes a slight diminution in the value of c.

By Molesworth's Kutter, when $r=3$ feet an increase in the slope from 1 in 1,000 to 1 in 40 causes a greater proportional increase in the coefficient than Kutter gives, and when $r=5$ feet the value of the coefficient does not diminish with the increase of slope, but, on the contrary, it increases with the increase in slope, and its value is the same as when $r=3$ feet.

3. By Kutter's formula (2) when the hydraulic mean depth is equal to 3.281 feet (1 meter), the value of c is *constant* for all slopes, and is $=\frac{1.811}{n}$ which in this $=\frac{1.811}{.013}=139.31$.

Let $r=3.281$ feet, and, therefore, $\sqrt{r}=\sqrt{3.281}=1.811$, substitute this value in formula (2) for $\sqrt{r}$, and we have

$$C=\frac{41.6+\frac{1.811}{n}+\frac{.00281}{s}}{1+\left(41.6-\frac{.00281}{s}\right)\frac{n}{1.811}}$$

and

$$\therefore\ C=\frac{1.811}{n} \text{ and when } n=0.13,$$

$$C=139\ 31.$$

This is the only instance, I believe, where Kutter's formula (2) gives a *constant* coefficient with a change of slope. By Molesworth's Kutter, on the contrary, the value of c changes with every change of slope when $r=3.281$ feet.

It is evident that Molesworth's formula was adopted in order to simplify the application of Kutter's formula (2), but its simplification is of no practical use as it gives very inaccurate results. As shown above, with the exception of its application to one diameter, the formula is not Kutter's, although in appearance bearing a resemblance to it. However, a modification of Kutter's formula can be made, simpler in form than even Molesworth's Kutter, and giving results near enough for all practical purposes to those obtained by the use of the more complicated Kutter formula (2).

The value of C in Kutter's formula (2) with a slope of 1 in 1,000 and $n=.013$, is thus expressed:

$$C=\frac{41.6+\frac{1.811}{.013}+\frac{.00281}{.001}}{1+\left(41.6+\frac{00281}{.001}\right)\frac{.013}{\sqrt{r}}}$$

and

$$\therefore\ C=\frac{183.72}{1+44.41\times\frac{.013}{\sqrt{r}}} \quad . \quad (5)$$

The following table will show the value of the coefficient c for several slopes and diameters according to formulæ:

	Molesworth's Kutter (3) C=	Kutter's Formula (2) C=	Formula (5) C=
6 inches diameter, slope 1 in 40	86.9	71.5	69.5
6 " " " 1 in 1000	85.3	69.5	69.5
4 feet " " 1 in 400	87.2	116.0	115.5
4 " " " 1 in 1000	85.3	116.5	116.5
8 " " " 1 in 700	85.8	130.5	130.5
8 " " " 1 in 2600	82.9	129 8	130.5

This table shows the close agreement of formula (5) with Kutter's formula (2), and it also shows the inaccurate results obtained by the use of Molesworth's Kutter (3).

The first column of this table shows that a formula with a *constant* value of $c=85$, that is,

$$V=85\sqrt{rs} \quad . \quad . \quad . \quad (6)$$

will give results differing in an extreme case, only 2½ per cent. from Molesworth's Kutter, and in the greater number of cases, differing only about one per cent.

The second column of the table shows the wide range of the coefficient c, by Kutter's formula (2), from 69.5 to 130.5 to suit the different changes in the hydraulic mean depth and slope.

The objection to the old formulæ was that they gave velocities too high for small pipes and channels, and too low for large pipes and channels.

The following table will show that the same inaccurate results are obtained by the use of Molesworth's Kutter (3):

	Velocity in feet per second by		
	Molesworth (3).	Kutter (2).	Formula (5)
6 inches diameter, slope 1 in 40	4.86	4.00	3.89
6 " " " 1 in 1000	0.95	0.78	0.78
4 feet " " 1 in 400	4.36	5 85	5.83
4 " " " 1 in 1000	2.70	3.68	3.68
8 " " " 1 in 700	4.59	6.97	6.97
8 " " " 1 in 2500	2.30	3.60	3.62

This table shows that there is a wide difference between the velocities obtained by Molesworth's Kutter (3) and Kutter's formula (2), and it further shows that for the slopes usually adopted in practice for pipes, sewers, conduits, etc., that it is for slopes not flatter than two feet per mile, or 1 in 2640, formula (5) will give velocities that for all practical purposes may be considered almost identical with the velocities obtained by Kutter's formula (2). The difference is generally less than one per cent., and it seldom reaches three per cent.

Mr. L. D'A. Jackson, C. E., in his "Hydraulic Manual," and Mr. R. Herring, C. E, in a paper read before the Am. Soc. C. E., in 1878, extend the range of materials to which the different values of n adopted by Kutter apply.

A table of the value of n for differeut materials, compiled from Kutter, Jackson and Herring, is herewith given, and this value of n applies also in each instance to the surfaces of other materials, equally rough.

n=.009. Well planed timber, in perfect order and alignment; otherwise, perhaps .010 would be suitable.

n=.010. Plaster in pure cement; planed timber; glazed, coated or enameled stoneware and iron pipes; glazed surfaces of every sort in perfect order.

n=.011. Plaster in cement with one-third sand, in good condition; also, for iron, cement and terra cotta pipes, well jointed and in best order.

n=.012. Unplaned timber when perfectly continuous on the inside. Flumes.

n=.013. Ashlar and well laid brickwork; ordinary metal; earthenware and stoneware pipe in good condition, but not new; cement and terra cotta pipe not well jointed nor in perfect order; plaster and planed wood in imperfect or inferior condition; and generally the materials mentioned with n=.010, when in imperfect or inferior condition.

n=.015. Second class or rough-faced brickwork; well dressed stonework; foul and slightly tuberculated iron; cement and terra cotta pipes with imperfect joints and in bad order; and canvas lining on wooden frames.

n=.017. Brickwork, ashlar and stoneware in an inferior condition; tuberculated iron pipes; rubble in cement or plaster, in good order; fine gravel, well rammed, $\frac{1}{3}$ to $\frac{2}{3}$ inches diameter; and generally the materials mentioned with $n=.013$ when in bad order and condition.

$n=.020$. Rubble in cement, in an inferior condition; coarse rubble, rough set, in a normal condition, coarse rubble, set dry; ruined brickwork and masonry; coarse gravel, well rammed, from 1 to $1\frac{1}{3}$ inches diameter; canals with beds and banks of very firm, regular gravel carefully trimmed and punned in defective places; rough rubble; with bed partially covered with silt and mud; rectangular wooden troughs with battens on the inside two inches apart.

$n=.0225$. Coarse, dry-set rubble in bad condition.

The accuracy of the results by Kutter's formula depends on the proper selection of the value of n for the surface of the material over which the water flows.

Again referring to the simplified form of Kutter's formula (5); if, in this equation, we call the numerator on the right hand side of the equation K for any value of n we have

$$C=\frac{K}{1+44.41\times\frac{n}{\sqrt{rs}}}$$

$$\text{and } V=\left\{\frac{K}{1+44.41\times\frac{n}{\sqrt{r}}}\right\}\sqrt{rs} \quad . \quad (7)$$

In the following table the value of K is given for the several values of n already referred to.

n.	K.	.	K.
.009	245.63	.015	165.14
.010	225.51	.017	150.94
.011	209.05	.020	134 96
.012	195.33	.0225	124.90
.013	183.72		

If, therefore, in the application of formula (7), within the limits of n as given in the table, and within the limits of slope of 1 in 2640 as already explained, we substitute for n and K their values found on the same line in table, and also the value of $\sqrt{r}$ we have a simplified form of Kutter's formula.

For instance, when $n=.011$ and $D=2$ feet, we have

$$V=\left\{\frac{209.05}{1+\left(44.41\times\frac{.011}{.707}\right)}\right\}\times\sqrt{rs} \quad (8)$$

TABLE GIVING VALUE OF $\sqrt{r}$.

Diameter. Feet.	Diameter. Inches.	$\sqrt{r}$.	Diameter. Feet.	Diameter. Inches.	$\sqrt{r}$.
0	5	0.323	2	6	0.790
0	6	0.354	2	9	0.829
0	7	0.382	3	0	0.866
0	8	0.408	3	3	0.901
0	9	0.433	3	6	0.935
0	10	0.456	3	9	0.968
0	11	0 479	4	0	1.000
1	0	0.500	4	3	1.031
1	1	0 520	4	6	1.061
1	2	0.540	4	9	1 089
1	3	0 559	5	0	1.118
1	4	0.577	5	3	1.146
1	5	0.595	5	6	1.173
1	6	0.612	5	9	1.199
1	7	0.629	6	0	1.225
1	8	0.646	6	6	1.275
1	9	0.661	7	0	1.323
1	10	0.677	7	6	1.369
1	11	0.692	8	0	1 414
2	0	0.707	9	0	1.500
2	1	0.722	10	0	1.581
2	2	0.736	11	0	1.658
2	3	0.750	12	0	1.732
2	4	0.764	13	0	1.803
2	5	0 777	14	0	1.871

To prevent possible difficulties on the waterway through a lack of water in the summer months, the Leeds and Liverpool Canal Company has constructed a storage reservoir to hold a hundred million gallons of water, at Barrowford, near Colne, for the benefit of the Lancashire portion of the system, and is building another at Winterburn, near Skipton, which is to have a capacity for three hundred million gallons, for the protection of Yorkshire interests on the canal.

UNAPPROVED ARMOR-CLADS.

From "The Engineer."

One of those awkward things designated "an open secret" has lately appeared with regard to the projected armor-clads the Trafalgar and the Nile. These two ships, the construction of which is just being commenced, will be the largest ships in the British Navy, and will each cost, with her armament, a million sterling. It might be supposed that the construction of these enormous and costly vessels would not be entered upon without the most careful consideration of everything which can appertain to their efficiency as engines of war. Larger than the Inflexible—though not to any marked extent—these ships might be expected to embody, in their structure and equipment, the most advanced ideas as to offensive and defensive power. In nothing ought these ships to fall behind their competitors, whether at home or abroad. Yet on the very threshold of this affair we are met with the astounding statement that the design on which these two sister ships are to be constructed is *minus* the approval of the late Director of Naval Construction, Sir N. Barnaby, and also of that gentleman's successor, Mr. W. H. White. Neither of these eminent naval architects identifies his reputation with these coming armor-clads. Neither one nor the other designed them, and we believe we are right in saying that the opposition of Sir N. Barnaby to the construction of these ships was and is of a very emphatic character. With regard to Mr. White, it may be sufficient to say that he simply withholds his concurrence from the proposal to build ships of such a type. The question arises, therefore—Who designed these ships? Not only so, but who is to be held responsible for them when they are finished? The design could not have dropped from the clouds; but we fear that the responsibility concerning it is of a very hazy description. We need not suppose that the design is actually bad *per se.* It is sufficient to fear that it is bad relatively. A Lord Mayor's coach might be very admirably planned and properly built, but it would be a very poor substitute for a locomotive. This is the kind of objection which applies to the Nile and Trafalgar. They may be very good ships in themselves, but the British Navy wants something else. As the most costly and largest ships in the whole fleet, they ought not merely to exhibit superiority to the other ships of the navy, but they ought to show the maximum effect producible from the expenditure that is to be devoted to them. In this they will infallibly fail, and their inception is marked by absurdity, as falling dismally short of what is required of the latest and most costly of British iron-clads.

We shall doubtless be asked for the particulars on which this indictment is founded. First, with regard to the armor. It is said that these ships are to have steel-faced armor 20 inches thick. This is no great achievement, seeing that the Inflexible has armor of 24 inches. The latter, being of iron, is probably inferior to the steel-faced plates of the new ships. But why not retain the thickness of two feet as a maximum, and couple with this the increased resisting power due to the face of steel? The 110-ton guns of the Italian Navy have penetrated 19 inches of steel-faced armor, so strongly backed that we may rest assured the 20 inches on the Trafalgar or the Nile would yield to the blow. But this does not end the story. The armor is not 20 inches everywhere. A concession has been made to Sir Edward Reed by lengthening the belt along the water-line, with the inevitable result of thinning the armor upon the citadel. As a consequence, the heart of the ship is accessible to the enemy's fire. It is putting armor upon a man's legs and thinning the breastplate. The man may save his shins and get his heart pierced. After all, the belt does not extend the whole length of the ship, at least one-third of the water-line being left without this defence, the sole protection there being the under-water armored deck, for which Sir E. Reed generally expresses such profound contempt. From a consideration of the armor we may proceed to a survey of the guns. Here, indeed, we witness a falling off of a most extraordinary character. The Inflexible carries her four guns of 80 tons each. But these two armor-clads, embodying somebody's latest ideas, are to have nothing heavier than breech-loaders of 66 or 68 tons, four being in each ship, carried in two turrets. That these guns are more powerful than those of the Inflexible is no answer to the objection that they are not so powerful as they ought to be. How do they stand in comparison with the 110-ton guns of the Italian fleet? Even our own Benbow, one of the despised "Admiral" class, will carry a couple of 110-ton guns. Again, in the element of speed what do we find? The projected rate is 16 knots. An attempt is made to get up a belief that the speed will be 18 knots. But this is mere conjecture, and when we remember that the practice now is to make the contractor specifically undertake the highest practicable speed, or very nearly so, there is no reason to expect that the coming ships will exceed the proposed rate by any important amount. Perhaps half a knot more may be looked for, but nothing further is probable. That the wish should be father to the thought concerning this higher rate of speed is readily accounted for. The Italia, just about to commence her steam trials, is expected to realize 18 knots, and anything less from the British ships would be intolerable. Commenced eight or nine years ago, the Italian monsters, Italia and Lepanto, took their start in a period when there was less light on the armor-clad question than now exists. The year 1886 is not as 1877 or 1878, so far as naval armaments are concerned. We do not say that a ship of 12,000 tons displacement can be reasonably expected to vie upon all points with one of 13,500, but assuredly she ought not to lag so far behind as to carry guns of 68 tons instead of 110 tons, and to have a speed of 16 knots as opposed to 18, with armor somewhat thinner than that of the foreigner.

We grant that the armor-clad question is one of great difficulty. So it has been from the first; but more especially now. The difficulty culminates at last in a conflict of opinion between the Board of Admirality and its technical advisers. It may be said that the question is rather one of policy than of naval architecture. To a certain extent this may be true, yet one element overlaps the other in a manner which renders a complete severance impossible. Sir N. Barnaby does not absolutely object to armor-clads, neither does Mr. W. H. White. But seeing that we have a certain number of iron-clads already in the navy, the question arises as to what is the real need of the present hour. The two authorities just named are perhaps better able to estimate the merits and defects of different classes of ships than the usual members of a Board of Admiralty. Minds technically trained may be supposed to discern with peculiar readiness the weak points in a ship of given design. The defects which now beset the armor-clads are doubtless realized with peculiar keenness by those who have most to do with the introduction of such ships. If ever there was need for a Committee of Inquiry into this matter, it is now. Some years ago we had a Committee on Designs for Ships-of-War. Such a committee need be appointed again, and there is this happy feature with regard to the suggestion, that it has the support both of Sir E. Reed and Mr. W. H. White, while to these names may be doubtless added that of Sir N. Barnaby. In the current number of *Harper's Magazine* Sir E Reed has an article on "The British Navy," which partially revives the old controversy concerning the Inflexible, and reiterates to the full the furious criticisms put forth by the writer in his letters to the *Times* with regard to the "Admiral" class of armor-clads as well as other ships. Sir Edward declares that the "whole series of so-called first-class iron-clads, of which only about one-third of the length has been protected by armor, are quite unfit to take a place in any European line of battle." The present condition of the British Navy is spoken of as "deplorable." One cause of this degeneracy is said to be the sustained attempt of successive Governments to keep the naval expenditure within or near to a fixed annual amount. Hence, the size and cost of our first-class ships have been cut down to suit a financial pressure. Of course, this argument makes no reflection on the naval architects concerned in designing the ships in question. But Sir E. Reed complains that another source of mischief has consisted in reducing the extent of armor carried by the principal vessels, rendering them, in his opinion, quite unfit to take part, with any reasonable hope of success, in any general engagement. Certain ships which the authorities consider to be armored Sir E. Reed refuses to recognize as such, and in this way as many as a dozen are struck off the list, namely, the Ajax, Agamemnon, Anson, Benbow, Camperdown, Collingwood, Colossus, Edinburgh, Howe, Rodney, Imperieuse, and Warspite. To this there is an addition of two ships of 10,400 tons displacement, with 18-inch armor, and five cruisers of 5,000 tons displacent, with 10-inch armor, recently ordered by the Admiralty to be built by contract. The objection to these ships is that, although they have some armor on their sides, "they are liable to capsize at sea from injuries inflicted on their unarmored parts." The Inflexible is omitted from the list, "out of compassion for those officers of the Admiralty who have long ago repented those trying compromises with conscience, by aid of which they expressed some slight confidence in her ability to float upright with her unarmored ends badly damaged." With this sarcastic stroke, Sir E. Reed intimates that, although his condemnation of the Inflexible has been refuted by a thoroughly qualified tribunal, he is "of the same opinion still."

That Sir E. Reed should be thus disposed to criticise ships which do not represent his own ideas, is, of course, to be expected. But to this we have now to add that two responsible advisers of the Admiralty are far from satisfied with certain recent designs. Sir N. Barnaby is free now to say what he likes, but the question is not merely one between himself and Sir E. Reed. These two authorities may controvert each other to any extent, but the interest of the public lies in knowing what is the real state of the Navy, and what are the prospects for the future. If our ships are defective, as Sir E. Reed declares, the fact should be placed beyond the reach of controversy. If the attack is unreasonable and groundless, let the public mind be reassured. If the coming Nile and Trafalgar, though uncondemned by Sir E. Reed, are not what they ought to be, let the design be altered while alteration is practicable. A properly constituted committee to investigate all these points is the need of the hour. If such a committee should be appointed—as we trust will be the case—one result, we expect, will be this, that they will advise caution in laying down any more armor-clads. But if such a committee is to be of any service, it must be more expeditious in doing its work, and more unanimous in its verdict than committees of the kind have been heretofore. Better no committee at all than one which will merely serve as an excuse to baffle inquiry.

THE CAUSE OF EROSION IN THE BORE OF GUNS.

By Captain A Laufroy, of the Marine Artillery.

From Abstracts of the Institution of Civil Engineers.

The author commences with a proposition already enunciated in several works on ballistics, viz., "That the erosion of the bore of a gun results from the escape of the powder-gases at high tension through narrow orifices, such as the vent or windage of the projectile." The essay is divided into six chapters. (1 and 2) Historical, deal with smooth-bore guns, guns with few grooves, and the modern polygroove rifling. After citing numerous experiments with various pieces of the above description, the author concludes on the polygroove system as follows:—viz., "That erosion always commences in the upper parts of the bore, and is divided into two distinct zones separated by an interval less attacked." The first zone is in the forward part of the cone of the powder-chamber, and often embraces the origin of the grooves. The second, which is always the most important after a prolonged firing, is at a distance from the commencement of the rifling, greater as the powder is more progressive. The lands are always less attacked than the neighboring grooves, sometimes they are intact. In time, the erosion extends over the circumference of the bore, at the positions of the two zones, but the top is always most injured. Other things being equal, the erosion develops as much more rapidly as the calibre is greater, and more quickly in bronze than in steel. Tool-marks or defects in metal in the upper part only of the powder-chamber are increased rapidly. After prolonged firing, an increase in the diameter of the bore is found chiefly in the shot-chamber, where the greatest erosion occurs. At the same time the ring of the projectile advances further up the cone, joining the powder-chamber to the bore.

The length of service of a gun is almost always limited by the loss of velocity and accuracy occasioned by erosion.

The wear of the rings, almost nothing at the commencement of firing, increases with the service of the gun.

For the first round of each series in a gun, the wear of the ring is about double that of the succeeding rounds (Report 826, 1879).

Chapter III. is a theoretical study of the mode of production of erosion in the bores of guns made since 1870.

The author states that when a gun is fired, it expands under the action of the powder-gas, which exerts a certain tension on the interior of the bore in a circular sense. When the gun is in one piece, this expansion of the bore is proportional to the calibre and interior pressure; according to the formula of General Virgile it is in inverse ratio of the modulus of elasticity, and diminishes when the thickness of the tube increases.

But large guns are composed of several pieces, which, if they have the same modulus of elasticity, require a fresh formula to express the relations of the circular tension and interior pressure on the bore, owing to the shrinkage employed to build up the gun. This formula is given, and the author, with the object of proving that the erosion commences in the upper part of the bore at the point occupied by the driving ring of the projectile when the maximum pressure occurs, and that all things being equal, it is greater as the calibre increases, proceeds to consider the ring of the projectile in three positions in the bore: (1) In the forward part of the cone at the commencement of the bore. (2) A little to the rear of the last position. (3) At the rear of the cone—the gun being taken as a smooth-bore, with the powder-chamber larger than the bore, and connected with it by a cone.

The second zone of erosion is next dealt with, this being a consequence of the first. The theory that the principal zone is caused by blows from the projectile, is questioned, as in this case the lands should suffer most, whereas it is the grooves that are most injured; it is not denied that blows are given by the projectile, but it is suggested that these will be reduced, as also the escape of gas, by increased forcing of the rotating rings. In considering the wear of the driving rings, on the hypothesis that the walls of the gun act as a file, for helicoid rifling the author gives a formula showing the wear to be proportional to the tangent of the final inclination of the grooves and the square of the initial velocity, and considers it advantageous to increase the number of the grooves. To diminish the wear as much as possible, and to preserve the ballistic properties of the gun, the author suggests a parabolic form of rifling, in which the pressure will be little at the commencement of movement, that is, at the parts most eroded; but in choosing a form of rifling, the wear, and also the maximum circular pressure exerted by the lands on the ring, must be taken into account.

Suggesting an interior design for a gun, the author adopts for the shot-chamber a cone sufficiently long for the ring to be tightly in contact at the moment of maximum pressure. The angle of this cone has been approximately determined by experiment, the length should be a little more than the distance, which in guns of the same calibre already proved, separates the initial position of the driving-ring and the mass of the erosion. The suggested modifications entail an increase in the diameter of the fillet of the driving-ring, which must be fixed by experiment.

The simplest solution from the manufacturing point of view consists in making a second cone to follow the cone of supports for the ring of a projectile, this cone having a greater inclination, the commencement of the grooves being well in advance of the driving-ring of the projectile when sent home.

SOME POINTS IN ELECTRICAL DISTRIBUTION.

By Professor GEORGE FORBES.

From the "Journal of the Society of Arts."

When I had the honor, just a year ago, to give a course of Cantor Lectures to this Society, on the distribution of electricity, the subject had not till then been treated in a systematic manner. I had then occasion to speak in strong terms of the methods habitually adopted, and subsequent experience has confirmed me in the justness of my criticisms. I gave a fairly complete account of the practical systems of laying electric mains which were at the disposal of the engineer when designing a system of distribution; but in the course of only three lectures it was impossible to do justice equally to all systems. When I was this year asked to read a paper before the Society, I eagerly availed myself of the opportunity to take up the straggling threads, and say a few words on the subjects which were previously but inadequately treated.

Allow me to remind you that, in my lectures, I described five different ways of laying the mains, each one depending upon a different method of connecting the dynamo machines and lamps. Three of these may be called direct systems, and two indirect. Each system has special advantages when applied to suitable cases, and when an engineer is designing a scheme of distribution he carefully considers the *pros* and *cons* of each system as applied to the special case, and very often he has to go through the whole calculations of the scheme according to several different systems. And here let me repeat, what I have often stated before, that no amount of labor and expense in these preliminary calculations should be grudged, as the ultimate saving effected by the careful selection of a suitable and economical system may easily range to 50 per cent. or more on the total cost of the installation.

The three direct systems are the parallel, series, and parallel-series methods of attaching lamps to the main conductors.* The two indirect systems are with the use of secondary batteries and secondary generators. Each of these systems is capable of being varied in the details of its application, and each is specially applicable to particular cases.

In a parallel system, each lamp is attached by wires to the two main conductors, and thus to the two terminals of the dynamo. This is its characteristic feature, viz., that the lamps are all metallically connected with the terminals of the machines.

In the series system, the conductor going through the district has its two ends connected one to each pole of the dynamo. But wherever there is a lamp the conductor is severed, and each terminal of the lamp is attached to one of the severed ends.

In the parallel-series arrangement the district is divided into sections. The first section and the last section have each a conductor attached to one terminal of the dynamo. The other conductor of the first section extends also through the second section, but no farther. Another conductor extends through the second and third sections, another through the third and fourth, and so on. In each section the two wires from each lamp are attached to the two conductors of that section.

The first, or parallel system, is generally most suitable for small installations, but the cost of conductors becomes extravagant when the area is extended, except in very special cases. The series system is at present only used for arc lights, sometimes with the insertion of a few glow lamps in parallel to replace an arc lamp.

The third system is admirably suited in every case where the number of lamps in use at any time is constant, and may perhaps be modified so as to be applicable to other cases. Smaller conductors can be used on this system than on the first, and this effects a very great economy.

* In my Cantor Lectures I used the terms multiple arc, series, and multiple series. I prefer the terms now advocated.

Having recalled these points to your notice, I need say no more, as I treated these three systems and their modifications very fully in my Cantor Lectures.

I thought I had spoken strongly enough about the enormous cost of the main conductors, and the necessity for selecting that size of conductor which is the most economical. We must not use too small a conductor, for then the waste of energy in heating the conductors would be enormous. Nor must we use too large a conductor, for this means buried capital. We must select that size which balances one cause of loss against the other, so as to give the maximum economy.

I find, however, that, while this axiom has been accepted as such in this country, some writers from America still try to uphold the fallacious views which have hitherto been in vogue here. I have noticed more than one criticism from America, by people asserting themselves to be connected in some way with some of the Edison companies, who protest against my statement that the three-wire system effects an economy of copper of only 25 per cent. over a two-wire system. The difference between us is that I start with the *axiom* that we are to use the most economical size of conductor. My critics start with the *assumption* that they shall use a conductor which shall waste exactly 10 per cent. of the energy. In this way they use a conductor which is not the most economical, and they show a saving of 62½ per cent. of copper over the two-wire system, but with a possible extra waste of energy of 62½ per cent. I said in my Cantor Lectures, and I repeat it this evening, that the manipulation of figures may suit American financiers, but it is not electrical engineering.

Before proceeding to discuss the indirect methods of distributing electricity, which is the main point I wish to touch upon to-night, I wish to supplement my remarks on series lighting by a statement of what has been done in the last year. I expressed a hope that more attention might be given to the lighting of houses by glow lamps in series. I further showed that it was only by means of a constant current flowing through glow lamps in series that the regulation of each lamp could possibly be effected on economical principles. This regulation must be accomplished by altering the length of the filament in the lamp. This has never yet been done, but if inventors once realize the importance of the object to be attained, I feel sure that we shall not have long to wait for the solution of the problem. Now I am delighted to be able to inform you that during the past year at least one inventor has been applying himself to the placing of glow lamps in series. Mr. Bernstein, who has paid so much attention to the system of glow lamps, has worked out the problem of using lamps of low pressure and large current in series. He has boldly taken extreme measures, and proposes to use lamps of 6 volts and 10 ampères. And here he has got over a difficulty I referred to in my Cantor Lectures. I said that there was no economical way of preventing a broken lamp from extinguishing all the others on the series. Passing part of the current through a shunt whose resistance is 100 times that of the lamp would be very expensive if we had in use lamps of the ordinary type, but with a lamp whose resistance is a fraction of an ohm, the expense would be trifling. When the lamp breaks, the current in the shunt is increased so as to release a contact which short-circuits both the lamp and the shunt.

I still think, however, that the loss of energy by heat conduction at the terminals may be very great in lamps of so low a resistance; Mr. Bernstein tells me it is ten per cent. Still I can well foresee that, even if a very sensible loss of energy occurred, the economy and convenience of using such a system might be amply sufficient to warrant its adoption in many cases.

I congratulate Mr. Bernstein on his work in the past, and would urge him to develop this idea more fully, and I can assure him that I, for one, will give the fullest consideration to the system when preparing the plans for electric light installations.

I should like also to take this opportunity of congratulating other makers of electrical appliances on the advances which have been made since the date of my Cantor Lectures. I should like especially to congratulate Mr. Swan on the improvements he has made in the manufacture of glow lamps; the Messrs. Siemens and Messrs. Crompton on their successful construction of very large dynamos; Messrs. Elwell and Parker on their great improvements in the details of construction of dynamos and motors; and the Electrical Power and Storage Company on the continued improvements in their secondary batteries. I would equally congratulate Messrs. Willans and Crompton for the continued improvements in steam-engine governors, for keeping the current from a dynamo or the pressure at any point in the circuit constant; likewise Mr. Ferranti for having brought out an electric current meter which promises to fulfil all the wants of engineers and the public in this direction; and last, but by no means least, Messrs. Woodhouse and Rawson for various new devices which will go far to assist in designing and carrying out many schemes of lighting; and I would specially mention their automatic cut-out, adjustable to any strength of current, which, though not so new as some other devices, has only been brought prominently to my notice during the past year, and whose simplicity and reliability give me great confidence in employing it. I must not fail to include here, as a subject for congratulation, the rising esteem in which secondary generators are held, and the improvements which have been made in their manufacture.

When I add to this list the admirable lamp-holder of Mr. Alfred Swan, Varley's adjustable carbon resistances, and other small but useful accessories, I think you will agree with me that the facilities at the disposal of the engineer for designing a satisfactory scheme of electric lighting, and which have been added to his store during the past year, are very abundant.

About one of these appliances I should like to add a few words:

First, I may say that the Electric Lighting Act was rendered abortive, if for no other reason, simply for the want of an electric-current meter which was in all points satisfactory. In the year 1882, a patent was taken out for a meter in which the current passing round an electro-magnet created a field where mercury was placed, which rotated when the current passed through the mercury from the center to the exterior of the field. If the magnetism be proportional to the current and the friction be proportional to the square of the velocity, then the number of turns completed in any time is a direct measure of the total quantity of electricity which has flowed through the meter in that time. The marked improvements introduced into this meter by Mr. Ferranti consist in the perfection of the magnetic circuit, and the introduction of an almost frictionless mechanism for correcting the revolutions, and showing them on dials like a gas-meter.

I have many of these appliances on the table, which any members of the audience may examine at the conclusion of the paper.

In referring to my Cantor lectures, let me make a few remarks about a double table which I introduced to assist engineers in calculating the size of mains required in any installation. These tables have been copied into a number of technical journals and books of reference, but in nearly every case there is no word of explanation how to use them. I have found these tables of such paramount convenience, that I think it right to call attention to them once more. The economical size of main depends upon three variable factors—the price of laying down a ton of copper mains, the interest to be charged on the capital sunk in mains, and the value of an electrical horse-power for the number of hours that it is to be utilized during the year. My table is divided into two parts. Look along the line in the second part, which relates to the percentage on capital which you propose to use, until you come to the column relating to that price of copper which you propose to use, and you then find a number printed which we may call the auxiliary number. Now take the first part of the table and look along the line which relates to that value of a year-horse-power which you propose to use, until you find the auxiliary number; the heading of that column of figures tells you the size of main per 1,000 ampères which is most economical to use according to the data you have employed.

I will now remind you of the position in which we were left after a full discussion in the Cantor Lectures of the three direct systems of distribution. The parallel system, or the three-wire system, is admirably adapted in cases where the farthest lamp of the district is within two hundred yards of the central station. So soon as you go to greater distances, the cost begins to increase in an alarming ratio. Hence this system would be applicable to a large district only by having engines and dynamos put down at a very large number of small stations. Now, a station is not worked economically unless the engine-driver and stoker are fully employed, and the maximum economy cannot be reached with less than about 1,000 horse-power. Thus, the parallel system is only applicable to cities so densely populated as to have a consumption of about 10,000 16-candle power lamps in a radius of two hundred yards. But in most districts of this class space is valuable, and a large number of such stations would be very expensive. We must then, in the parallel system of distribution, be content to work at a cost which is above that of the ideal of economy. There are many cases where the great simplicity of such a system does actually make it worth while to sacrifice this ideal of economy, and when an engineer is consulted on such matters, it is his duty to estimate the exact loss from not strictly following the ideal economical rules before adopting or rejecting this system. In order to make a parallel system effective, the central station must use distributing boxes, the methods of placing which are described in my Cantor Lectures.

The cure for all these evils would be found if a thoroughly satisfactory system on the parallel-series plan were known. In that case, high tension electricity might be used, involving smaller conductors. Thus, the central station might be at a distance, where land is cheap, and it might be of any size, so that all the works would be in the same place, as they are in gas distribution. Here the only departure from the ideal of economy lies in the length of the conductors to the district which has the supply. But these conductors are comparatively small, and no engineer would recommend the adoption of such a system unless he found that the economy of having the works out of the expensive district counterbalanced the extra expense in mains.

Now I regret to be compelled to say that, after discussing all the ingenious plans on the parallel-series system proposed by Mr. Edison and others, I arrived at the conclusion that at this time there is no parallel-series system of distribution which is quite satisfactory. I do not say that such a system cannot be devised, but I do say that at this moment no such system is available to the electrical engineer, except in the case where the same quantity of electrical energy is consumed in any district at all hours during which the current is being used. There are some cases where it will pay to insert equivalent resistances when lamps are put out. These cases are rare, but they must not be lost sight of by the engineer.

Having in the Cantor Lectures discussed all the direct systems of distribution, I will complete my outline of this part of the engineer's profession by an examination of the two indirect methods which I formerly touched upon only lightly, viz., secondary batteries and secondary generators.

Secondary Batteries.

During the electric boom (as Americans would call it) of 1882, the secondary battery took a prominent part, not so much for what it had done as from what was expected it would. It was said that since no one would think of sending gas from the retorts without storing it in a gasholder, so the same must be done with electricity. Every one will admit that it is most desirable that this should be done, and I am glad to say that secondary batteries have been improved to such an extent that there is every reason to hope that this will be done, always provided that the companies who supply them, do not expect the public to repay them for the hundreds of thousands of pounds which may have been thrown away in the past.

I have been given to test about a dozen different kinds of secondary batteries, of which I have found some four or five to be good, and the others mostly worthless. I can say this, that at the present moment secondary batteries can be supplied by certain makers which are to be relied on with careful usage, and which give us 70 to 80 per cent. return for the energy expended.

Now, it might be asked, what are the advantages of storing the energy if you lose 25 per cent. by doing so? The first advantage is that a breakdown in the machinery does not then interfere with the supply. The second advantage is that the steadiness of the supply does not depend upon the speed of moving machinery. The third and great economical advantage is that your expensive engines and dynamos are paying interest twenty-four hours of the day, instead of only a few hours, by doing their work, and a smaller supply of engines and dynamos suffices.

Now, this is all very well, so far as having secondary batteries at the point of supply is concerned, but it does not help us much so far in the great problem which we have attacked, viz., that of electrical distribution. But the improvement of secondary batteries led to great hopes of a cheap system of distribution. It was said, "Put your generating station at a distance, on cheap ground, carry a current with high potential through light conductors to the district to be lighted. Pass the current through some thousand accumulators in series, placing these in batches of fifty (say) each, in cellars, to light up a small district." The original idea was to keep the service wires permanently attached to the two ends of each set of fifty cells.

Now, this plan is very beautiful if only it would work. But it will not work. The consumption being small from some of the cellars, and large from others, and the same charging current going through all of them the cells become overcharged in many cases, and this is injurious.

Another plan was proposed, which I described in my Cantor Lectures. This was to introduce an arrangement to indicate when the cells were fully charged. By having two complete sets of batteries in each cellar, the indicator caused a rocking switch to act, which switched the fully charged battery off from the charging mains on to the service mains, and at the same time switched the second set, which had, up to that time been supplying the service mains, on to the charging mains. Here I would point out that, independently of the fact that we have no reliable indicator to show when the cells are fully charged, this only moves the difficulty back one step. For it will often happen that both sets are fully charged, and yet we are obliged to send currents through one of them. This plan was tried at Colchester, but of course it had to be abandoned. If we had a true indicator to show when the cells are fully charged, the more sensible plan of using it seems to be to cause the indicator to disconnect the cells from the charging mains, and connect the charging mains metallically. There would, of course, be a great fall of potential in lamps immediately after switching off the supply current, but the charging of the cells might be done by day or after midnight, during which time lamps are not very much used. I think that even this small difficulty might be got over by causing the indicator when it acts to increase the number of cells which lead to the lamps.

I suppose the most reliable indicators which could be used are those depending upon the specific gravity of the solution or the weight of the negative (oxydized) plate. Unfortunately it is seldom found that a number of cells working in series become charged at the same time.

In fact, it is not very generally known that the most satisfactory plan for charging secondary batteries is to do so in quantity or parallel. When this is done, every cell is fully charged exactly at the same time, and all give off gas at the same moment. If there be any possibility of short-circuiting, however, fusible plugs or other cut-outs must be inserted.*

To have a thoroughly satisfactory installation, it is necessary that the cells may be left in their secluded retreats, without attention, for long periods. I think I can safely say that cells can be so left if fairly treated. But the question is whether any scheme of distribution hitherto considered does give them fair treatment. If attendants have to be continually going around to inspect cells, this expense must be carefully calculated so far as is possible, and taken into account.

Now let me say a few words as to the improvements in secondary batteries. First, I may say that there is now no doubt that they can be made, and are made, by several makers of so good a construction that they can be used for several years. I will not fix the number of years, because none of the most perfect ones have yet failed. Secondly,

* Even in this case we may have a partial short-circuit, which will drain the current and yet will not cut out the cell.

it seems to be conclusively proved that not only does no buckling take place, but there is no fluting or blistering if the plates are originally good, and if the air has not been allowed to reach them. Thirdly, we know that in overcharging them we do not injure them, but merely waste current. These are important facts, and are all we want for an installation where the state of the cells can be always under examination. For central station lighting we want something more. We want the cells to take current from the dynamos when they require it. For this we must have an indicator on the cells to work a switch, according to the state of charge of the current. Up to the present no satisfactory master-cell has been devised. Those which depend on the gas given off do not act equally promptly with currents of different strength. The most promising system is one in which the state of the cell is shown by the specific gravity of the liquid. Very little ingenuity is required to develop this into a satisfactory system. But we cannot depend upon one master-cell, since it is only when charging in parallel that all cells act alike. If we have several master-cells in each battery, all of which must act together to cut off the dynamo, I think we might depend upon their action. The function of the switch is—first, when the E. M. F. of the battery is too high, to cut out the dynamo circuit from the battery, to give a through connection to the dynamo current, and to switch in two additional cells to the lamp circuit; second, when the E. M. F. of the battery is too low, to break the charging current, to connect the battery to it, and to cut off two cells from the lamp circuit. These are all ordinary things which can easily be done.

But even without automatic action of this sort there are many large installations where it would be economical to use secondary batteries, even if attendants had to be continually examining the state of the cells. The engineer who is designing an installation, if he does his duty, calculates the cost of every method of working which can be feasible.

The cost is, of course, an important item, and were it not that this system introduces a great saving in copper conductors and machinery, it would often be too expensive to work. We may take the cost of batteries at about £3 per lamp of 60 watts. The saving in copper conductors is proportional to the number of batteries put in series. There is also a saving in dynamos and engines. If we take four hours as the average time of using the lamps, we charge them, say, for six hours in the day-time, and we use the dynamos as well as the batteries, during the greater part of the night. Thus we require batteries and dynamos for only about one-half of the number of lamps generally in use. This brings the cost of batteries down to £1 10s. per lamp, and the cost of dynamos and engines from about £1 per lamp (the usual cost for a direct service) to 10s. per lamp. This makes a total cost of £2 per lamp, as against £1 by a direct service. When we have made a further reduction for diminished size of conductors, and an increase for additional attendance, we are in a position to compare the two systems. But these figures vary so enormously that it is impossible to estimate them unless one has the details before him. We may say safely, however, that in large districts there is economy in secondary batteries, and in small districts in a direct service. But the advantage of not being dependent on the constant perfection of machinery is very great, and avoids the necessity for so complete a duplication of the parts. Of course the cost of working must also be made out, allowing for a loss of at least 20 per cent. in transforming through the secondary batteries.

The number of ways of using secondary batteries is great, but there are no engineering difficulties in the distribution, and I may, therefore, content myself with having drawn attention to the general advantages of using them.

Among the many special appliances used in this kind of work I am glad to be able to show you some useful things supplied by the Electrical Power and Storage Company.

Perhaps the most important of these is a switch for large currents, in which a number of concentric tubes have a longitudinal slot into which the arm of the switch is forced. The split tubes have a certain amount of spring, and literally cut into the arm of the switch, and so make good metallic contact. The one before you has been thoroughly tested with 1,500 ampères passing through it.

Another appliance is an automatic switch to reduce to number of cells in the lamp circuit when the dynamo is charging the cells, and *vice versa*.

A third is a cut-out to prevent damage to the charging dynamo by an accidental falling off of speed. It has this peculiarity, that it puts the battery in circuit again so soon as the dynamo resumes it functions.

In concluding this part of my subject I would draw your attention to the scheme of Lighting the Vienna Opera House. The dynamos are by Messrs. Crompton, of 72,000 watts each, and are driven by direct-acting Willans and Robinson engines. I am told that they give an electrical horse-power for 3.7 lbs. of coal. The secondary batteries are supplied by the Electrical Power and Storage Company. The three-wire system is adopted, 110 cells are ordinarily in use with each circuit, and 6 additional ones are available to keep the electric pressure constant.

Secondary Generators.

I now come to speak of secondary generators, and since the principles which regulate their action are rather novel, it may be well if I spend a little more time in describing their action than I would otherwise do in a lecture treating chiefly of the manner of laying main conductors.

Everyone knows the principle of the induction coil. It consists of a core of iron surrounded by a coil of insulated wire called the primary coil, and by another one of insulated wire called the secondary coil. The secondary usually contains a larger number of turns and finer wire than the primary. The current in the primary is alternately made and broken by a simple automatic means. This magnetizes and demagnetizes the iron core. This is equivalent to introducing and withdrawing a magnet into and out of the secondary coil, and sets up currents in the secondary coil.

The electromotive force created in each turn of the secondary coil is measured by the number of magnetizations per second, and by the strength of the magnetization. The latter is generally proportional to the number of turns in the primary, and to the current flowing through it. Thus the electromotive force in the secondary coil depends (1), on the number of turns in the primary; (2), on the number of turns in the secondary; (3), on the strength of current in the primary; and (4), on the number of makes and breaks in the primary current. Thus, by having a large number of turns in the secondary coil, and a small number in the primary, a very high electromotive force can be obtained from a small battery connected with the primary.

If, on the other hand, a high-tension interrupted current were sent through the fine-wire coil we could get a large current from the thick-wire coil.

Now, to feed a number of glow lamps in parallel we require a large current, but this requires a large conductor. Here it was proposed to use a high-tension alternate current (which acts just like an interrupted current) by a thin conductor from the works to the place of consumption, and there to transform it into a current of large quantity.

Then, again, another idea was thrown out. This was to carry the alternate current by a thin conductor around a large district, and at intervals to pass it through the first coil of induction coils, using the second coil to supply the lamps. Thus we should have a high-tension current disconnected from the service conductors, and furnishing them all with a low-tension current.

Induction coils used in this way have been called secondary generators or transformers. The perfection of manufacture of such apparatus consists in getting a maximum of induction and a minimum of heating. This has been admirably accomplished in the generators of Messrs. Goulard and Gibbs. Instead of wire, the coils are made of copper disks, or flat rings split at one point, and with ears projecting outward at the split. These discs alternately belong to the primary and secondary circuit, and successive discs of each circuit have the ears soldered together in such an order as to make up a spiral. The iron core is, of course, made of iron.

Although the even discs belong to the primary and the odd ones to the secondary, it does not follow that alternate discs should be coupled together. We may couple the 1st, 5th, 9th, &c., together, and also the 3d, 7th, 11th, &c., so as to form two secondary circuits, which may be combined in parallel. The number of possible modifications of this sort is very great.

When the primary coil is magnetizing and demagnetizing the iron core, the latter sets up a counter electromotive force in the coil, and thus the current is largely diminished. But when there is no external resistance in the secondary coil, that coil being short circuited, then any magnetization and demagnetization of the core starts a current in the secondary coil, opposite in direction to that in the primary and almost equal to it. Thus the iron cannot get much magnetized, for it is surrounded by two opposing currents almost equal in amount. In this case, therefore, the primary has little or no counter electromotive force opposing it, and consequently it flows more freely. This explains a thing which often puzzles the beginner, viz., that with a constant electromotive force in the dynamo the current in the primary is stronger when the secondary circuit is closed than when it is open.

Very little energy is expended in magnetizing and demagnetizing iron wires. Thus there is really no loss of energy in the transformation, except that due to the heating of the conductors, of which the coils are constructed, which is equal to the square of the current multiplied by the resistance. The loss of energy, which could not be accounted for, has been shown by Professor Ferraris to be less than 1 per cent., and the practical efficiency of the generator amounts to as much as 95 per cent.

The theory of the secondary generators is very like that of the alternate current dynamo, if the reversals of magnetism of the armature were given by reversing the currents in the field magnets instead of by mechanical motion.

Coming now to distribution by secondary generators we find we must use the same principles as in direct distribution.

Parallel Distribution.—Let us take this case first. To do this economically we might lead two thin wires over the district and couple secondary generators to them. The condition of being able to have constant electric pressure in the lamps is that the electric pressure at the terminals of the primary should be constant. Here we meet the same difficulty as was experienced in direct supply. Consider three generators—1, 2, 3. If the lamps are all on in all three cases, then the pressure for No. 3 is less than for No. 2, and that again is less than for No. 1. Suppose you try to rectify this by using lamps of lower pressure at the far station. In this case suppose the lamps in No. 2 are extinguished, then the pressure in No. 3 will go up and tend to injure the lamps. If you try to correct this at the central station you will lower the pressure of No. 1 till perhaps it only burns red. This difficulty is exactly the same as in the direct service. The remedy is of the same kind. You must use the generators as distributing boxes (see my Cantor Lectures, 1885), with separate wires from the engine to each generator, each one being fed with a different pressure from the engine house. There is no objection to it except (1) that you must use a large number of conductors, and (2) you must introduce the full pressure of the high tension current into each house.

Finally, we come to distribution by generators in series. Here we have the best effect. A single wire goes round the circuit; if a double wire is used, to prevent affecting telephones, it is half the weight, and generators are alternately put on one wire and the other all round the district, and each pair of wires ends at a point far from the station. Suppose we use 10,000 volts, we may have 100 generators in series, each using 100 volts, or we may make any other arrangement. If it were done as I say, then following out the data of my Cantor Lectures, a wire of one square inch section will carry current enough for 100,000 lamps each consuming 60 watts.

In this arrangement we must send a constant current through the circuit. This is actually done by the introduction of resistances. It ought to be done either by an electric governor on the steam-engine, or by compound winding the alternate current machine, a matter about which there is no difficulty at all.

But how are we to attain to constant electric pressure in the lamps when we have got our constant current? This is a problem which has puzzled many people, and many have come to the conclusion that it is impossible to do it without mechanism. This used to be done by automatically introducing the iron core farther or less far into the coils. It is now done without any relative movement of the parts. This is the last triumph which has been added to a series of laborious experiments which, year by year, have brought us nearer to a solution of our difficulties. I am not at liberty to explain the *modus operandi*, but I have seen it at work, and it is very satisfactory.

The theory of secondary generators has been so little studied, except by specialists, that I have thought it might be advantageous to many if I added to this paper the formulæ which represent the electric current and pressure as depending upon the resistances and mutual induction of the various parts. These data will be found in an Appendix to the present paper.

I do not think it would be consistent with the objects of this paper to describe the specific differences between different kinds of secondary generators, or to attempt to give reasons for choosing one of these forms rather than another. I would merely draw attention to the brilliant experiments on self-induction by Professor Hughes, described in his introductory address as president to the Society of Telegraph Engineers and of Electricians. Professor Hughes has discovered a new and hitherto unnoticed source of waste of energy in self-induction, to remedy which it is essential to have the coils of the secondary generator made of discs.

I should also like, before leaving the subject, to dispel a growing error from the minds of some electricians. In speaking of different secondary generators, some persons are in the habit of speaking of one inventor's generator being used on a parallel system, another on a series system. This distinction is quite illusory. A generator made on any system is equally suitable for all kinds of distribution, and if an inventor states that his generator is only suited for one system of distribution he displays his ignorance, and shows that he has yet much to learn before he can say he understands the theory of secondary generators.

Last year, when speaking in my Cantor Lectures, I said that the Grosvenor Gallery installation would be followed with interest by engineers. I considered that it was a new test. Up to that time the method had been applied only to light districts where the number of lamps was constant. It was not proved that the method was suitable to the cases where lamps might at any moment be extinguished. Two things were necessary for this, (1) regulation of the current from the dynamo, and (2) automatic regulation of the electric pressure in the secondary circuit. Neither of these had then been accomplished in a manner which satisfied me, and I certainly considered it was a very bold step on the part of the Sir Coutts Lindsay to adopt a system which was then so imperfect.

I am satisfied now that self-regulation of the secondary circuit is sufficiently perfect for practical purposes, even when the generators are in series; and I have pointed out to Messrs. Gaulard and Gibbs a further development which, in my opinion, will make their system even more perfect. The one weak point in the Grosvenor Gallery installation is the regulation of the current from the dynamo. Out of the four or five different methods by means of which this can be done, the worst has been applied up to this time, viz., hand-regulation. The result is a frequent flicker in the lights. Still, when we consider that seven miles of route has been covered by the wires of this small association, and that on the whole great satisfaction is expressed by the users of the light, I must say that Sir Coutts Lindsay and his friends are to be congratulated on the great steps they have made toward success.

In conclusion, I wish briefly to allude to the present condition of electric lighting, and the prospects of economical distribution from central stations.

I have always maintained that there were three causes which retarded the progress of electric lighting:—(1), financial speculation; (2), the Electric Lighting Act of 1882; and (3), the unsuitability of the schemes of electrical distribution propounded by the contractors. I will say a few words on each in turn.

From the year 1881 to 1883 this country was the scene of a most senseless speculation, started by clever men of business, who took advantage of the interest in electric lighting caused by the

Paris and Crystal Palace Exhibitions, and supported by dupes whose ignorance of electrical matters was only equaled by their want of common sense as business men. These men combined to purchase for large sums the right to use the apparatus of some particular manufacturing firm in a special locality. They never asked any competent person whether this firm's apparatus was better or worse than that upon which there were no royalties to pay. Those who were not clever enough to get out of the affair before the bubble burst were the sufferers, and the consequence was a panic in connection with electric lighting which has hardly yet subsided.

With matured knowledge confidence is again being restored, because the public learn from competent and disinterested persons that economical electric lighting can be accomplished without the necessity for paying the heavy royalties formerly demanded.

I trust that the warning of 1882-3 will not be lost on financiers, and that they will not be misled by untried but tempting schemes unsupported by capable men of science.

The next cause which has deterred electric lighting is the Act of 1882. This is an Act to give undertakers the right to break up streets in order to lay conductors, under certain conditions. It is these conditions which are so unjust. Some of our legislators, looking at the monopolies which exist in gas supply, are afraid that electric lighters will raise another monopoly. Consequently, they determined to hamper the electric lighting industry with conditions different to those imposed upon gas, and more stringent. They succeeded well, for they laid down such conditions that no sane man would invest in such a speculation. You would have thought it natural, I doubt not, that if the gas monopoly was truly so very irksome, the encouragement of a rival illuminant would have been the best cure for the evil, whereas our legislators acted as if they were parties interested in maintaining the gas monopoly, for they imposed such restrictions as rendered it impossible for electricity to be supplied to the public. Let me name one of their wise provisions: At the end of twenty-one years the local authorities can, if they please, buy from the company supplying electricity the whole of their plant at the price of old material, without paying a farthing for goodwill or future profits, or past expenses in experimental and unprofitable work.

If then a company, after twenty-one years, were just making headway, and paying a dividend of 5 per cent. on their capital, the corporation would buy them up for perhaps a third of that capital, and get 15 per cent. But the case is even worse if the company is not yet earning a fair dividend, for then the corporation may hang over the company like a usurer over his victim, and each seven years it has the right to purchase the plant or not, and on the same terms as before.

Now, I agree with those who contend that electricity should be allowed to compete with gas under the same disabilities, and with the same advantages. This is not doubling a monopoly; it is splitting it into two, and destroying the monopoly, by allowing competition. If our legislators are not trying to uphold the gas monopoly, they must take this view. In any case the public have shown that they will not submit to be deprived by legislation of this illuminant. The Board of Trade, I hear, have perceived their error, and are prepared to yield a little; but if they do not enable us to have electricity supplied to us, we, the public, must force their hand.

Still, electric lighting is not quite dependent on this Act. Local authorities have no penalties, and I would strongly urge them to take the matter up, for we have now arrived at a stage when it is safe and profitable to establish electric lighting on a large scale.

Again, you must remember that the disabilities of the Act apply only to those who lay their conductors underground and wish to break up the street. Sir Coutts Lindsay has taught us how to defy the Electric Lighting Act by passing the wires overhead. Those wires do not suffer like telegraph wires in snow storms, for the electric current melts the snow.

The third cause which deterred the progress of electric lighting, was the unsuitability of schemes of distribution which were proposed. I was impressed with this weak point at an early date.

Sir William Thomson was the first to touch on the matter when he announced his law of the economical size of conductors. But the engineer had no tables to guide him as to the safety of these sizes of conductors in the matter of heating. I attacked this problem first in order to clear the way for scientific methods of dealing with distribution. In a paper read before the Society of Telegraph Engineers and of Electricians, in 1883, I computed from the facts well known to physicists, the heating of different-sized conductors with different currents, whether the conductors were bare, insulated or buried. I had already, in a communication to the British Association in 1882, shown by experimental evidence, that the generally accepted laws required modification when we dealt with small wires.

The way being thus cleared, I attacked the problem of distribution generally, studying the various schemes which had been proposed or put in practice. My conclusions were published in the Cantor Lectures in 1885, and the most useful result was to announce a series of definite rules which must be attended to in order to provide an economical distribution. Since then some progress has been made, and the present paper will, I hope, bring the subject pretty well up to date.

The work which I undertook has been laborious, but it has been a very humble effort. I have brought forward hardly a single fact which could not have been foreseen by the competent engineer. But I think I have saved others from wasting their energy in repeating much of the work which is laborious; and I also trust that the outcome is a set of rules to guide those engineers whose purely scientific knowledge may be a little defective from falling into the gross errors which have been so apparent in nearly all attempts at lighting by electricity on a large scale which have been made in the past.

I now close the subject for a time, and if the labor I have bestowed upon it leads in any slight measure to establishing one department of electrical engineering on a sound scientific basis, I shall feel that in the work I have undertaken I have been of some little use to my generation.

Appendix.

The following formulæ give the currents and electromotive forces, on the assumption that the magnetism of the core varies as the sum of the currents in the two coils.

The E. M. F. of the dynamo is assumed as being:

$$E \sin, mt$$

Then the primary current $= I \sin (mt+\gamma)$

secondary current $= I' \sin (mt+\gamma')$

$$I^2 = E^2 \frac{C^2 + r'^2}{r^2 r'^2 + (r+r')^2 C}$$

$$I'^2 = E^2 \frac{C^2}{r^2 r'^2 + (r+r')^2 C^2}$$

Where C is a constant:

r = resistance of primary circuit;

r' = " secondary circuit.

Also the

potentials at primary terminals $= v$;

and " secondary terminals $= v'$;

where $v = V \sin. (mt+\varphi)$

$v' = V \sin. (mt+\varphi')$

$$V^2 = E^2 \frac{\rho^2 r'^2 + (\rho + r')^2 C^2}{r^2 r'^2 + (r+r')^2 C^3}$$

$$V'^2 = E^2 \frac{(r'+\rho')^2 C^2}{r^2 r'^2 + (r+r')^2 C^2}$$

ρ and ρ' being the resistances of the primary and secondary coils.

Discussion.

Professor Hughes, F. R. S., said in his latest researches he had found that the maximum induction in iron took place when the iron was in the round form. If it was flattened, so that the contiguous portions of the current became separated from each other, the current was very weak; it had not one-tenth of its previous capacity. In the case of copper wire flattened, the reduction in the self-induction was about 50 per cent. Taking iron wire and passing a current through it, if you wished to have a secondary current parallel to it, the self-induction prevented the current acting on the secondary coil; in fact, the force of the electric current was used up in doing internal work. By flattening it, it re-acted on another wire to its full force, so that the energy which would have been used in self-induction, was transformed into the secondary current. He had not the slightest doubt that if this method were adopted, enormously more power could be obtained from the secondary coil. When the two wires were flattened, the portions contiguous to each other did not re-act on each other with the same strength, but re acted on any portion near; consequently, when there was another flattened sheet superposed, you had it in the nearest possible proximity. It was very remarkable that the same results at which he had arrived theoretically should have been worked out experimentally by Messrs. Gaulard and Gibbs, and they had arrived at the best possible conditions he could conceive for constructing a secondary coil. He had only one fault to find with it; the generator itself seemed perfect, but it required intermittent currents, and, therefore, it seemed to him there must be a loss in the line. He had been much interested in the paper, and hoped Professor Forbes would continue his investigations on this subject which he had made peculiarly his own.

M. Gaulard (who spoke in French) thanked Professor Forbes for his remarks upon the actual conditions and future prospects of the apparatus with which he was associated. He also thanked Professor Hughes for his expressions respecting the mode of construction adopted, and in answer to the objection as to the great loss caused by the use of alternate currents for leads of great length, he said he could rely upon the experiments made with their apparatus, and reassure Professor Hughes entirely on this subject. Their apparatus was constructed with two parallel circuits, forming spirals in the same direction. In order to obtain in the secondary circuit a variable electromotive force, they had contrived to unite in parallel and inverse directions the two circuits, and they had found that if in these conditions they sent through them an alternating current, the difference of potential at the ends of the spirals was directly proportioned to the resistance in the leads. If, on the other hand, they interposed in one of the connections a resistance, they found that the difference of potential at the two ends of the secondary circuit was, to a certain extent, directly proportioned to that resistance. From these observations it followed that if the leads consist of two parallel wires, and currents in opposite directions are sent through, not only no phenomenon of induction on the outer external circuit can appear, but no self-induction on these two leads can exist any more. As a practical demonstration of these results he quoted the experiments made in 1884, near Turin, on a line of 80 kilometers, which the kindness of the Telegraph Administrators of the Government had allowed them to establish on their telegraph poles. By reason of the limited space, the two wires (out and home) were placed at a distance of 15 centimeters from each other, and at the same distance from the telegraph wires. When properly insulated, the telegraph engineers ascertained that their apparatus had not been affected by any induction, and the jury, in determining the loss by the resistance in the leads, likewise ascertained that this loss was equal to the produce of the square of the intensity of the current in the lead by its own resistance.

Mr. Kapp said he did not know much about the distribution of electricity, but he should like to add one more to the list of improvements which had been placed at the service of the electrical engineer, and that was the reduction which had been made in the speed of the dynamo. If electricity were to be distributed for domestic use, you must be quite sure that there should be no breakdown; that was an imperative necessity, and the best way to ensure that was not to drive the machine at too high a rate of speed. Within the last few years the tendency had been to reduce the speed of dynamos by designing them in a more scientific way, making use of stronger fields, and of altogether better mechanical construction. Machines were now running at half the speed of those constructed a few years ago, and in this way the chances of failure were enormously reduced.

Mr B. Drake remarked that Professor Forbes had drawn attention to the different ways in which electricity might be distributed for lighting purposes, but had not fully compared the relative advantages and disadvantages of the different systems. On behalf of secondary batteries, he would claim advantage in the practical impossibility of totally extinguishing a district through the failure of a single wire. No doubt there were many points which might be claimed on behalf of secondary generators, such as the first cost being less, and there being stronger metals in use, which would be likely to last longer than lead plates, but at the same time the contingency of a station being extinguished all at once was an important consideration, and the fact of the engine having to be run to its full power whenever all the lights were required would more than balance the small extra cost of the accumulators in the first instance. The question had been raised as to the different details of apparatus necessary in connection with secondary batteries; they had been experimenting with every kind of apparatus for the last eighteen months, with a view to ascertain how far it was really worth while to complicate the system by putting in automatic contrivances, and after designing all sorts of apparatus, they had come to the conclusion that the whole thing ought to be kept as simple as possible. For instance, Professor Forbes had referred to an apparatus by which, when the dynamo started charging, the number of cells in circuit might be reduced. That was a very easy mechanical problem to solve, and such an apparatus had been made; it was designed specially for train lighting, where an accumulator was to be placed in each carriage and charged in series, so that a train might be split up without difficulty, and accumulators charged in this way would really be a model of what was required on a larger scale for district lighting. Then they had to face the question of cutting off an extra cell as soon as the dynamo was put into the circuit; but it was found that the question of the accumulators being either fully charged or practically empty made so much difference to the electromotive force between the terminals, that to cut off any fixed number of cells was practically barely worth the trouble. When a cell was practically empty, you required only 2.2 volts to charge it with a certain current, whereas to get the same current through it when the cell was full required over 2.5; the cutting off of a definite number of cells was therefore practically not worth the cost of the apparatus. It was, however, found advisable to introduce some kind of automatic switch in any installation where the attendant ever had to leave the engine. There was again the question of the regularity of the light. If the engine power varied at all where secondary generators were used, that variation was transmitted throughout the whole district; if a bearing ran hot, all the lights felt it; and in addition to that, there was the variation which Professor Forbes now said had been nearly overcome, which was due to varied consumption at different points of the circuit. With secondary batteries none of these evils occurred, and if some apparatus could be made reliable for cutting them in and out when fully charged, it seemed to him the solution of the problem would be complete. He agreed with Professor Forbes that the specific gravity was the right principle to adopt in cutting out the accumulators, and that the master cell system would be much improved by having two master cells which would have to be completed before the automatic cut-out would work. The difficulty with the specific gravity apparatus was this: The carrier which carried the whole apparatus had to float as well as the hydrometer, and in order to do that, the cell containing it had to be enlarged. In that way the bulk of the acid was enlarged, and consequently, the range in specific gravity became so extremely small, that you could practically do nothing with the small variation of the hydrometer. On the other hand, with the extremely small space which was necessary to get any appreciable variation, you had to employ such a small apparatus, that you could hardly rely on its working properly. The only way to get any results was by a system of relays, and that was difficult near accumulators, because the contacts got corroded by the acid. No doubt the advocates of the other system would be able to point out objections to secondary batteries, and he should be much interested in hearing them.

Mr. Shoolbred said it had been stated that the difficulty of knowing the state in which secondary batteries were, when they were fully charged, and when they were getting exhausted, had been got over by the use of hydrometers. He should like to know if this had proved really successful.

Mr. Drake said he had just been explaining that the great difficulty was the confined space. He did not know of any case where they had been used practically for actuating switches automatically.

Mr. Mordey thought the carbon resistance gauge shown was very similar to that which had been made for years by the Brush Corporation, consisting of a series of small carbon plates in a case, with a screw or lever arrangement to enable the resistance to be varied by alteration in the pressure. The principle had been used by Mr. Brush in his automatic regulator. The original principle he believed was due to M. Clerat, who communicated it to Professor Hughes in 1867. With regard to lamps of low resistance, he might say that on some circuits at Eastbourne and also at Brighton, the plan had been in operation, not with so low a resistance as Mr. Bernstein used, but so low as to allow of three lamps in a group being used, instead of eight or nine; each lamp taking a current of 3.3 ampères, the normal working current being 10 ampères. The manipulation of a group of lamps was very much simplified when the number was reduced; and if it could be reduced to one, and a constant current could be maintained through the circuit, the perfection of simplification would be attained; but even where three had been used in a group, with about 15 volts at the terminals, the manipulation of each group was not a serious matter. Where people employed a large number of lights, they might object to turn out eight or ten, but the same objection did not apply to a group of three. He should like to ask if there was any advantage in using secondary generators in the manner shown in the diagram in parallel; it seemed to him that all the effect thus obtained could be obtained much better by the ordinary direct supply. The cost of leads and the whole of the problems connected with the question would be of much the same in each case. Another point in connection with secondary batteries was of great scientific interest, and that was as to the actual loss of energy in the iron of the core due to the rapid magnetization and demagnetization. There had been a great deal of discussion of late years as to whether any energy was really lost in this way, and it was a very difficult subject to work at, because it was almost impossible to eliminate the effect due to eddy currents, and that due to the turning over of the molecules, as Professor Hughes would call it. In an ordinary dynamo machine, where the reversal of polarity was not so rapid, only 400 or 500 revolutions a minute, and the molecules only required to be turned over 800 or 1,000 times a minute, the difficulty was not felt, but in secondary generator coils, where the reversal of magnetism took place thousands of times in a minute, it would be very different, and he should like to know if the actual loss had been ascertained.

M. Gaulard, in answer to the observations of Mr. Drake respecting the great loss which might result from the retardation in the molecular vibrations, produced by a very great number of alternations—an opinion based upon certain facts observed in the use of a current having 1,000 alternations per minute—he would point out again that, in the experiments made by the international jury of Turin upon the secondary generators by the most exact method, the calorimetric method, the current used had 16,000 alternations per minute; the yield had been proved to be 95 per cent. This is the greatest number of alternations obtained till now, by an alternate current machine of the largest type known, and perfectly sufficient, he thought, for producing the highest electromotive force which may be wanted from a practical point of view.

The Chairman drew attention to the several points which had been raised by Professor Forbes, and which had been brought out in the discussion, such as the relation of the size of conductor to the mode of distribution, and especially the part played by secondary batteries, and again, the important applications of secondary generators so ably explained by M. Gaulard. Now that electric lighting was not going forward with such hot haste as it was two or three years ago, those who were connected with it had more time to think about the best and most efficient methods of doing the work, and the lull would be found to be a time of great profit to electric lighting. We may be thankful to Professor Forbes for making the question of the size and arrangement of conductors so much his own, and for giving us the benefit of his researches in this direction. We must also thank him for so ably bringing before us in the Cantor Lectures, and in his paper this evening, the results of a great deal of thought and experiment on the different systems of lighting. Thanks to his and other researches, we may say that electric lighting is on a much more stable basis than it was three years ago. When it was stated that you could depend on getting out of storage batteries 70 or 80 per cent. of the energy employed, it was evident that a great step had been made during the last three years. Coming to the question of secondary generators, a very successful experiment had been made—indeed, it was almost more than an experiment—by Sir Coutts Lindsay. He might also refer to the experiment made some time ago by Messrs. Gaulard and Gibbs, in which they lighted up part of the Metropolitan Railway—from the Edgware Road station to Aldgate in one direction, and Notting Hill Gate in the other—from one central station. The apparatus exhibited this evening showed that even then they had made very great progress, and that they had gone far ahead of the position to which they had then attained.

Professor Forbes, in reply, said some of the points raised had been already answered. M. Gaulard had replied to Professor Hughes by telling him of the effect of the double line; and he would observe that in doubling the line it was not necessary to double the quantity of metal, because, as shown in the sketch of the series arrangement, when you doubled the line, you tapped both wires, and therefore made the wires half the section they would otherwise have been. He ought to have congratulated Mr. Kapp on the improvements he had effected, but he should congratulate him on increasing his magnetic induction and the capacity of his machine, more than on diminishing its speed. It was perfectly true there might be less chance of failure in a machine when running at half speed than at the speed it used to run, but at what a tremendous cost that safety was obtained. The machine ought to do double the amount of work it did at that reduced speed. When there was a central station to light, the dynamo must be run at a reduced speed, but it must be made up for in another way by increasing the size. When there were large districts to light, it would be economical to have large machines going at comparatively slow speeds. When Mr. Drake came to look at the paper, he thought he would find that he had given full credit to the advantage he had mentioned of a district never being put in darkness through one wire breaking. He was sorry to hear that the sum total of eighteen months work was, that they could not leave the batteries alone to automatic appliances to work themselves, and he trusted that Mr. Drake would reconsider that question. He hoped to see secondary batteries largely used in central station-lighting, but if it involved the necessity of attendants going round to look after them and switch them in and out, it would be a serious drawback to their introduction. He ought to have mentioned that it was Mr. Drake who originally suggested to him the use of two master cells. He could not give Mr. Shoolbred any more information with regard to the use of hydrometers than Mr. Drake had furnished. In reply to Mr. Mordey, of course he did not mean to say that the use of carbon plates as an adjustable resistance was new, but he drew attention to this instrument of Mr. Varley's because he believed it was new, and it possessed advantages he had not seen in any previous arrangement. It was perfectly adjustable by the screw, and did not require knocking on the table to shake the pieces apart, as he had found with Mr. Brush's apparatus. With regard to the advantage of using secondary generators in parallel, he would point out that if the station were at a great distance, very thin conductors might be used to the generators. You might use a primary circuit of any series, and take as the secondary coil a number of discs in parallel, and so use a high tension current, thousands of volts in the primary, and yet have only 100, or whatever was required, in the house, and have all the economy of thin conductors. With regard to the loss of energy in magnetizing and demagnetizing, he agreed with M. Gaulard that it was an extremely minute quantity which could not be detected; the loss when a core of iron wire was used was very small indeed.

THE WATER SUPPLY OF SOME GREAT CITIES.

From "The Builder."

The pure inland seas and mighty rivers of North America afford to the inhabitants of that quarter of the world an unstinted supply of water, for all purposes of navigation, cultivation, mechanical power, and domestic use. The Mississippi River alone drains an area of more than ten times the extent of the United Kingdom. The surface of the water of Lake Superior, at a level of 628 ft. above the sea, covers an area larger than that of the whole of Scotland. The length of the inland navigation, from the Straits of Belle Isle to Fond-du-Lac, at the head of Lake Superior, is 2,384 statute miles, and from the same point of starting to Chicago, on Lake Michigan, almost exactly the same distance; while the ocean navigation from Belle Isle to Liverpool measures only 2,234 statute miles. The Ohio River, from which the great city of Cincinnati derives its water supply, has a mean annual flow of 150,000 cubic ft. per second, and is 4,000 ft. wide when it falls into the Mississippi, nearly 1,100 miles above the mouth of the latter river. Lake Michigan, on the borders of which has risen the most rapidly-developed of all the great cities of the New World, namely, Chicago, has an area of 23,000 square miles. It is 320 miles long, 100 miles broad, 628 ft. above the level of the sea, and is said to be 100 ft. deep. The Croton River, at a distance of 33 miles above New York, is raised by a dam to a height of 166 ft. above mean-tide level at that city, and its waters, led thence in an aqueduct, flow at a level which provides for the supply of 90 per cent. of the area of that city by gravitation. Thus, whether we regard abundance and purity of water, or natural facilities for its distribution by gravitation, every imaginable form of convenience to the dweller in cities for the supply of his need of this great necessary of life is offered by nature in the United States. Nor is there any part of the surface of the globe in which the skill and perseverance of man have been more efficient in making the best of the gifts of nature.

It is thus of no small interest to the residents of older and more densely-populated countries, especially in those localities where the rapid increase of population has attained such a density that the citizens could not be supplied with enough water from the skies above them, even if every drop that fell over the districts in question could be caught and stored for use, to ask what the genius of the American engineer has done to supply the need of the urban population of the chief great cities of that continent from the inexhaustible stores of its lakes, rivers, and running and falling waters.

In the United States exist (or existed at the date of the last census) but ten cities of each of which the population exceeds 200,000 souls. In the United Kingdom, excluding the metropolis, there were also, at the date of the last census, only ten cities of each of which the population exceeded 200,000 souls.

On the Continent of Europe twenty-four capitals and great seaport towns exceed that population; but neither are the data so well ascertained, nor the conditions so distinctly characteristic, as is the case with the cities of the United States. The $3\frac{1}{2}$ million residents of our ten great centers of population, and chiefly those of the metropolis, who form a yet larger body of water consumers, may well look with interest to the outcome of the experience of 5 millions of townsfolk (in 1880, 4,855,000), of kindred race, placed amid the unfailing waters of North America.

Of these great cities, three, viz., New York, Brooklyn, and San Francisco, have laid out in the aggregate about the same sum that has been expended on the London waterworks, in order to obtain the advantage of a supply by gravitation, for an aggregate population little more than half that of London. Boston also depends on gravitation, drawing its supplies from the Sudbury river, and the Lakes Cochituate and Mystic. Philadelphia pumps to reservoirs, from the Schuylkill and Delaware rivers. Baltimore depends partly on gravitation and partly on pumping, taking its supplies from Jones's Falls and Gunpowder Rivers. St. Louis and New Orleans pump to reservoirs from the Mississippi, as does Cincinnati from the Ohio. And Chicago, as original in its mode of procuring water as in so many other features of its masterly engineering, draws its supply from the pure water of Lake Michigan, through a tunnel of two miles in length under the bed of the lake, fed through a down-pipe at the end in a depth of 32 ft. of water. Alone among these great Western cities, Chicago (owing to its low level) adopts the old-fashioned English mode of pumping to a stand-pipe. Of all the ten cities, the cost at Chicago is the lowest, whether as regards outlay of capital in proportion to the number of inhabitants, or working cost per million of gallons. On the other hand, so freely is the water dispensed in Chicago, that the daily delivery averages 109 gallons per inhabitant. It is of interest to take note of the growth of the city which, so far as present information goes, has at once the cheapest and the most copious water-supply in the world, although, owing to the liberality with which it is dispensed, the annual cost per inhabitant is higher than that in either New York or Philadelphia.

The population of Chicago, which, in 1830 was seventy persons, became in

1840	4,583
1850	29,963
1860	112,170
1870	295,977
1880	503,185

Language fails to add to the force of these figures. From 1870 to 1880 the increase has been nearly sixty souls per day.

The waterworks of Chicago, as they existed at the date of Sir Charles A. Hartley's visit in 1873, were described by that engineer in a paper communicated to the Institution of Civil Engineers in the following year. It was found, Sir Charles says, by careful borings, that a bed of compact blue clay, at least 100 ft. thick, underlay the thin crust of silt and sand which formed the bottom of the lake. On this bottom, at the distance, as before said, of two miles from the shore, was formed an artificial island to serve as the locality for a shaft at the lakeward end of the tunnel. For this purpose a crib or timber frame, of a pentagonal plan, 90 ft. in diameter, 40 ft. high, and with walls 25 ft. thick, was constructed on shore, towed to the selected spot, and filled, in fifteen prepared compartments, with 6,000 cubic yards of stone to sink it to the bottom of the lake. The top of this structure, when settled into place, stood 5 ft. above the water. and in the center of the mass was a sort of open well, of about 30 ft. in diameter, Within this framework, which contained 50,000 cubic ft. of whole 12-in. timbers, a column of seven cast-iron pipes, of 9 ft. in diameter, and of a total length of 63 ft., was sunk through the clay to 31 ft. below the bottom of the lake. The clay was excavated within as the pipe sank, and the tunnel was started from below to meet that previously commenced from the shore. This gallery is nearly circular in section, being 5 ft. 2 in. in depth, and 5 ft. in width, and consists of two rings of brick in cement, 8 in. thick. It was started from each end, the lake end being commenced eighteen months later than the work from the shore. The land shaft is sunk to 70 ft. below the level of the lake, and 77 ft. below that of the ground, so that the tunnel has a landward fall of 7 ft. in the whole distance. The two excavations met at about one quarter of the distance from the crib to the shore.

Four steam pumping-engines were provided for the service of the city, but at the commencement of 1873 a new double-beam engine was started as a relief. This, which is said to be the largest pumping-engine in the United States, has two 70-in. steam cylinders with 10-ft. stroke, and works two pumps of 57 in. diameter, delivering 36 millions of gallons of water in twenty-four hours. If worked together with the other engines there is a combined capacity of 75,000,000 gallons per twenty-four hours. A stand-pipe, 140 ft. above the level of the lake, is protected by a stone tower 170 ft. high. The pumps are considered to force the water to a height of 132 ft., but in the daytime the delivery is said not to rise higher than the second story of the houses. The water is supplied through thirty-eight miles of mains, the largest of which have a diameter of thirty-six inches.

The power of delivering a daily supply of water equal to half of that now demanded by the wants of 4,000,000 of Londoners was not, however, enough to slake the thirst of Chicago. A second intake-shaft and tunnel were in progress at the time of Sir Charles Hartley's visit in 1873, and a land tunnel, 7 ft. in diameter, was pierced for four miles westward of the lake, in order to supply a second set of pumping works to accommodate the extension of the city. By the year 1880, as we learn from Mr. J. J. R. Croes, the author of "Statistical Tables of the Water Works of the United States," the sum of £1,868,000 had been expended on the water-works of Chicago, the annual revenue from water rentals amounted to £206,000, and a mean quantity of 109½ gallons per head of the population was daily supplied.

With this enormous volume of water, and with the simplicity of arrangement which the unlimited supply and the low level of delivery render possible, it is not matter of wonder that the working cost of water delivery in Chicago is by far the lowest in the world. In the nine years ending in 1872 the cost of delivering a million gallons of water varied from 52s. to 32s. In 1882 it had fallen to 22s. But the revenue of the works amounted, in the last-named year, to £10.26 per million gallons, and the cost per inhabitant, owing to the copious nature of the supply, was 26 per cent. higher than that incurred in the same year by the inhabitants of London.

While Chicago is thus the cheapest of the great cities of the West, in the procurement, if not in the sale, of water, the lowest cost per inhabitant occurs in New York. We must, indeed, make exception in favor of San Francisco; but the figures stated with regard to the latter city are in some respects so anomalous that we await the result of inquiries made in the United States on the subject before quoting them to our readers. Of nine of the ten cities, certainly, New York is at the same time the cheapest, and the only one that supplies water at a less rate per inhabitant than the average price in London. Yet the capital laid out on the New York water-works is £5.84 per inhabitant, while that in Chicago is only £3.73 per inhabitant, and the working cost per million gallons is nearly twice as much in New York as in Chicago, while the revenue is only about 3 per cent. more.

The water supply of New York is provided by the construction of a dam across the valley drained by the Croton River, about six miles from its mouth, which raises the water to a height of 40 ft. above the original level at that point; or to 166 ft. above the mean-tide level at New York. From this dam to the Harlem River, which is crossed by an aqueduct containing eight arches each of 80 ft. span, and seven arches each of 50 ft. span, runs an uninterrupted conduit of stone and brick masonry, set in hydraulic cement, of thirty-three miles in length, including a tunnel through rock. The Harlem Aqueduct was built to carry two cast-iron pipes, each 4 ft. in diameter, at the level of 108 ft. above mean tide; but a 7½ ft. diameter pipe of boiler plate was laid down in their place. The masonry conduit is continued for two miles from the Harlem Bridge. Then the Manhattan Valley is crossed by syphon pipes, and two miles more of conduit and aqueduct brings the water to the received reservoir at New York. This reservoir, formed in two divisions, has an area of 31 acres, and a capacity of 150 millions of imperial gallons. It is connected with a distributing reservoir of an area of 4 acres, a depth of 36 ft., and a capacity of 20 millions of imperial gallons; an additional receiving reservoir of an area of 106 acres, and a capacity of 1,000 million gallons; and a new storage reservoir in the Croton Valley, of three times the last-named capacity, raises the combined capacity of the whole of above indicated reservoirs to 4,570,000,000 gallons. And yet another reservoir in the Croton Valley was in course of preparation, at the time referred to, with a capacity of 3,700,000,000 gallons; the object being, in case of the occurrence of long droughts, to provide for 82 days' consumption of the city, at the rate of 100 gallons per head, irrespective of the minimum daily flow of the Croton River, of 27,000,000 gallons.

For the supply of the higher section of the city, north of the Manhattan Valley, a high service reservoir is constructed, into which water is pumped by steam from the aqueduct near Harlem Bridge. And the very highest points are fed from a tank supported on a tower, near the last-named reservoir, at a height of 300 ft. above the sea. In 1882 the ordinary daily consumption of the city was 95,000,000 American, or ordinary wine, gallons of water; and the high service supply amounted to a further quantity of 11,605,630 American gallons. The cost of the works has attained the large figure of £7,000,000, or £5.84 per inhabitant. The annual revenue was £343,000, or 5.7s. per head, and the working cost was £70,000, or only 1.14s. per head. The daily supply per inhabitant was 74 imperial gallons.

An instructive comparison of the two opposite methods of supply by gravitation and by direct pumping is afforded by the statistics of the water supply of Chicago and of New York. In the former, where £3.73 per inhabitant has been laid out in the works we have enumerated, the cost of pumping to the height of 132 ft., and of the entire distribution, amounted (for an annual volume of 20,124 millions of gallons) to the incredibly low figure of £1.11 per million. In the later, where one-tenth only of the supply has to be pumped for about the same lift as at Chicago, the working cost for the delivery of 32,425 millions of gallons in the year 1882 was £2.18 per million. The sum of £5.84 per inhabitant had, as before said, been laid out on the works. If we allow the whole price of pumping and distribution at Chicago as an extra charge on the proportion of the New York supply that has to be pumped, we have a cost of £2 07 per million gallons for the working expenses of the gravitation supply, including the maintenance of its large reservoirs, forty miles of aqueduct, and its other works, against a cost of £1.11 per million for direct pumping; and this, too, with coal costing 28s. per ton.

It is thus evident that it is altogether idle to attempt to prescribe the cheapest method in which the water supply of any given locality can be effected without due consideration of all the features of the case. It is, of course, clear at the first glance that, other things being equal, it is cheaper to supply water by gravitation than by pumping, independent of the extra strength of pipes and fittings that is required in the latter case. But the cost of the storage works has at the same time to be taken into account; and that both as involving interest on money and cost of maintenance. The interest on the New York gravitation works, if taken per head of the population supplied, is, as we have shown, to that on the Chicago direct pumping works, as 5.84 to 3.73. But this is not all. The maintenance of these noble works, together with all the other working expenses of supply, raises the working cost at New York to nearly double that at Chicago.

Perhaps the nearest approach to a comparison of the same nature between towns of a certain magnitude in England is afforded by the cases of Worcester and of Plymouth. In the former city the water of the Severn, running through the place, is pumped to a reservoir, at a cost of £7.06 per million gallons. In the latter, from works first constructed in the reign of Queen Elizabeth, the waters penned up in a mountain valley are conducted through a leet or open channel, of some twelve miles in length, into reservoirs for distribution, close to Plymouth. The average cost is returned at figures that do not work out to more than £1.41 per million gallons. Here the cost of maintenance is very low, and comparatively little has been done to aid the resources provided by nature herself. With these two localities as instances of the cheapest water supplies in England may be compared the supply of Kingston-upon-Hull, where the water is drawn from two artesian wells, and pumped into service-reservoirs of a capacity of about two days' supply of the town. Here the working cost comes to £7.34 per million gallons, which is close upon that at Worcester. For the Kent company, among those of the metropolis, which also relies on pumping from springs, the cost comes to £8.95 per million gallons. It is readily intelligible why cost should be higher in the last case than in the two former; but the comparison tends to show that the cost of our urban supplies is, for the most part, very closely approaching the minimum possible under the physical features of the case. The cost to the consumers, in the exceptionally favorable case of Plymouth, according to the figures given in the Return of Urban Water supply (265, 1879), is at the rate of £7.01 per million gallons, which is a lower figure than that in either of the great cities of the United States. Water is sold by meter at Plymouth for 2d. per 1,000 gallons, which is equivalent to £8.33 per million. The rates outside the borough are 50 per cent. higher than within, averaging 3.33 per cent. on the rental. But the question of the amount of rate legally chargeable is always liable to so much complication, that any statement of it conveys little information, if compared to that mode of application which we have followed, viz., rate of cost per million gallons, and rate of charge per inhabitant; the two figures being connected with each other by the rate of daily supply. Correcting the population given in the Return of Urban Water-supply by the increase from 1871 to 1879, the cost of water per inhabitant at Plymouth is 2.4s. per annum, and the daily supply is 46 gallons per head.

ENGINEERING PROGRESS.

ABSTRACT OF THE INAUGURAL ADDRESS OF PRESIDENT PERRY FAIRFAX NURSEY OF THE SOCIETY OF ENGINEERS.

From "Iron."

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I THEREFORE pass on to other themes, and propose, in the next place, to bring under your notice, some of the greatest achievements of the modern engineer in directing the great sources of power in nature in one special department of engineering, and the insignificant results accruing therefrom as compared with those arising from the development and exertion of analogous forces by nature herself. I shall then ask you to bear with me whilst I allude to the advanced position of engineering science, and then point out how prone we sometimes are to be so dazzled by the brilliancy of the light of that science as to be unable to see, or, seeing, refuse to believe, that some of those marvelous workers of bygone ages ever possessed a scintilla of scientific knowledge as we understand it, because the evidence thereof has not come down to us in the shape of text-books or treatises, and because we cannot fathom, or do not understand, all the deeper principles underlying some of their most majestic creations. I shall then take you back with me towards the childhood of the world to see if we cannot discover in the long past, the well-defined shadows of some of those things which we deem to be of essentially modern creation. I think we shall find that the principles underlying some of the most remarkable inventions and discoveries ascribed to our own times were by no means unknown to the ancients, and that in some instances the inventions themselves have been distinctly anticipated.

In considering the results accomplished by the modern engineer in directing the forces of nature, my experiences with explosive compounds lead me to look at the question more particularly from this point of view. In our explosives we have one form of condensed or concentrated power, resulting from an ingenious and intimate admixture of all the elements which it is necessary should be united in combustion, including oxygen, so that in action they are independent of the atmosphere and will explode under water. Man thus, by simple means, collects, compresses and stores up some of the forces of nature in a portable and handy form, and at the proper moment releases them and utilizes their power by directing it against those formidable obstructions which it is sometimes found necessary to remove in the interests of material progress and civilization. By the application of heat in one form or another, this stored-up power in a high state of tension is instantaneously set free, and acts with a greater or less degree of intensity according to the nature and composition of the explosive. The most common forms of explosives are gunpowder, guncotton and dynamite, combustion in the first being comparatively slow, and in the two last inconceivably rapid. It is this rapid development of intense power in dynamite and its congeners that renders it so useful to the engineer in removing large masses of rock in a short time, and at a comparatively small cost. Although I have done a certain amount of blasting in ironstone mines and open workings, I cannot lay claim to having fired any very big charges. My heaviest blast was made with 115 lbs. of lithofracteur, a species of dynamite, possessing about the same strength, but exerting a greater rending power, and being a nitro-glycerine preparation. This was on the Jersey Harbor works, where Sir John Coode desired to remove, among other obstructions, a wall of rock which was standing out from the main rock, but running in a line with its face, there being a space of a few feet between the two. This wall was about 20 ft. high, 19 ft. long, and 12 ft. thick, the foot being exposed for a short time only at low water, and the rock being nearly covered at high water, ordinary tides, thus affording the advantage of the resistance of a good head of water for tamping. At low tide I planted my 115-lb. charge in the angle formed by the wall and the main rock, with the capped fuse inserted, which I led up to the top of the rock. At high water, which happened to be at midnight, I rowed out, landed, lighted my fuse, rowed away, and in a short time heard the low rumble of the subaqueous explosion, and the tumbling of the water. The next low tide revealed the wall of rock reduced to fragments and lying on the bottom, the explosion having also acted in a downward direction. It was computed by the engineer of the works and myself that at least 400 tons of rock had been dislodged by the blast. This gives about $3\frac{1}{2}$ tons per lb. of explosive used, which may be taken as a fair average of what it should do.

In the autumn of 1879 I witnessed two heavy blasts with gunpowder at some granite quarries on the western shores of Loch Fyne, near Inverary. The first of these blasts was effected with 3 tons of gunpowder at the Crarae quarry, which is about eight miles from Inverary, and the second with 5 tons, at the Furnace quarry, which is some two miles nearer that town; both quarries belong to Mr. Sim. The quarries present extensive faces, and it is mainly the faces which are brought down, the powder being disposed in galleries to the rear of the face, and as near as possible to the dividing joints of the rock. The mines were fired by electricity, the 3 tons of powder in the Crarae quarry bringing down an estimated aggregate of about 60,000 tons of granite, and the 5 tons at Furnace about 100,000. This gives in each case 10 tons of rock per pound of powder, but it is to be observed that the conditions of work were comparatively easy, the face only requiring a forward heave to detach and throw it down on to the floor of the quarry below.

There are two cases of heavy blasting with gunpowder on record, which I may here refer to in passing. The first of these was the removal of the Rounddown Cliff at Dover in 1843, in which operation 18,500 lbs., or $9\frac{1}{4}$ tons, of gunpowder were disposed in three separate charges, which were fired simultaneously by a voltaic battery. The second case was at Holyhead, when the harbor was being made. One of the heaviest blasts there was 12,000 lbs., or 6 tons, of gunpowder, divided up into several charges and ignited simultaneously by means of a platinum wire heated by a Grove battery. The total quantity of rock stated to have been removed by this blast was 40,000 tons, or 3.33 tons per pound of explosive.

In the early part of last year a considerable blast was effected with dynamite in a stone quarry at San Francisco. Four galleries were driven each 50 ft. into the rock, and were returned at the end at right angles, forming a letter L. The explosive, of which $5\frac{1}{2}$ tons were employed, was placed in the return galleries, the charges being tamped with debris. The four explosions were arranged to occur successively, the first to loosen the rock and make the work of the next easier, and so on with the second and third. It was estimated that the 11,000 lbs. of explosive had displaced 35,000 tons of rock, being a little over 3 tons per pound, and thus practically agreeing with my own experience.

The heaviest known blast, however, I believe to be that which was successfully accomplished last autumn at the entrance to East River, New York, known as Hell Gate, when 150 lbs. of nitro-glycerine compounds were exploded simultaneously in removing Flood Rock. Nine years previously, namely, in September, 1876, the most extensive blasting operation up to that date was successfully accomplished in the demolition of Hallett's Reef at the same place. The area then operated upon was three acres, and the weight of nitro-glycerine preparations (chiefly dynamite) used was about 25 tons, the quantity of rock demolished being estimated at over 63,000 cubic yards. Assuming the rock to weigh 2 tons to the cubic yard (that was the weight of the rock in Jersey), we have 126,000 tons of rock removed by 50,000 lbs. of explosive, or rather less than three tons per pound. After the removal of Hallett's Reef, operations were carried on at Flood Rock on the opposite side with a view to its removal, and by this means to render safe the navigation of the channel. On October 11, 1885, this object was successfully accomplished by the aid of 150 tons of explosives, which is six times as much as was used on Hallet's Reef, and which constitutes the biggest blasting operation on record. In this case, nine acres of rock were honeycombed, and charged with 75,000 lbs. of No. 1 dynamite, and 240,000 lbs. of rackarock, which is one of the potash class of explosives. The nine acres of rock had been pierced from below with four miles of tunneling in galleries, the floors of which were from 50 to 64 ft. below mean low tide, with walls of from 10 to 24 ft. thickness between them, and supported by 467 columns of rock, each 15 ft. square. In the columns and rock roof of these galleries nearly 14,000 holes, of an average depth of 9 ft., had been drilled, and each was charged with a 6-lb. cartridge of rackarock, and a 3-lb. cartridge of dynamite. These were all connected by a battery, so as to be exploded by a single electric spark. The shock of the explosion lasted about forty seconds, the visible results being the raising of an enormous volume of water to a height of 200 ft. into air. Upon subsiding, it developed a mass of broken rock, from which fire issued for a short time, but in two minutes more everything was quiet. No damage was occasioned to property, although a tremor caused by the explosion was felt at some distance. An examination of the rock showed that the explosion had been completely successful. General Newton, the chief engineer, states that it will probably cost half a million of dollars and take two years to remove the masses of broken rock. When the work is completed the channel will be 1,200 ft. wide, instead of 600, as at present, and 26 ft. deep, enabling ocean steamers to enter at all tides.

Such are some of the results produced by modern engineers with the aid of the most powerful explosives known. Great as they are, comparatively speaking, how utterly insignificant they appear when compared with the results of the development of some of the occult sources of power in nature, as illustrated by that gigantic earth-displacement which took place on August 26 and 27, 1883. I refer, of course, to the stupendous upheaval of Krakatoa on the coast of Java, the most formidable volcanic eruption recorded in modern times. It has been computed that the eruption and the tidal wave by which it was followed, swept away at least 50,000 human beings at a stroke. It caused the entire disappearance of an island about 3,000 ft. in height, and transformed the geography of the region of the Sunda Straits. The usual volcanic products including the finest particles, both solid and vaporous, were ejected into the air to a height that no man will ever say, for it is on record that for many miles around the scene of these devastating forces noon was as black as night, and darkness was all over the land for from thirty-six to forty hours. The scale on which the work was done was such that even the noise, the weakest part of it, was heard at a distance of 2,000 miles. The shivering of the island produced a wave of water 100 ft. high, which destroyed everything over which it swept, and left its mark on tidal registers nearly all over the world. The mere air-pulse produced by the last fearful cataclysm was strong enough to pass with its gradually widening circle nearly three times round the globe. It is easy to imagine that, with disruptive forces at work on this gigantic scale, millions of tons of matter, and perhaps millions of cubic miles of vapor, must have been hurled into the upper air. The coarser part of this matter would soon descend, as, indeed, was the experience of the crew of the British ship *Charles Ball*, Captain Watson, which vessel encountered the full force of the downpour of matter, being in the vicinity of the island of Krakatoa. The finely-divided particles, however, doubtless remained in suspension, and were probably the cause of the magnificent sunsets observed all over the world in the November and December following the eruption. Beside the sunsets, there was a peculiar appearance of the moon, which had at times a pale green tint, as noticed by myself and others. The remarkable sunsets of 1883 recurred in the autumn of 1884, although not by any means with such intensity and universality. These sun-glows were repeated in the autumn of last year, but with diminished frequency and brilliancy. They have served, however, to keep awake the discussion as to their real nature and cause, but whether they were due to volcanic or cosmical dust, or to some other undiscovered medium, is a point which has yet to be settled, if it ever can be. The theory that they were due to the Krakatoa eruption was not universally accepted at the time it was started; but, in the early part of 1884, M. Angot, in a communication to the French Academy of Sciences, directed attention to a parallel case which occurred in 1831, when there was a violent volcanic eruption, and a new island was thrown up in the Sicilian Sea, together with a quantity of ashes. For some time after the commencement of that outbreak, which lasted altogether for several months, brilliantly-colored sunsets were observable at many places on the Continent.

A singular circumstance is on record in connection with the Krakatoa eruption, which is worth referring to here. On August 26, 1883—the date of the vast upheaval—strange subterranean noises were heard in the island of Cayman-Brac, in the Caribbean Sea. This island is situated in 20° north latitude, and 80° west longitude, and to the South of Cuba. The inhabitants, who are tortoise fishers, were on that day alarmed by noises like the rolling of distant thunder, although the sky was perfectly clear. Seeing no signs of thunder, they imagined that some volcanic eruption was about to take place; but little by little the singular phenomenon diminished, and they ascertained it to be subterranean. Now, the Cayman group are the antipodes of Java, where the eruption took place. The supposition, therefore, that these subterranean noises were due to the Krakatoa volcano at once suggests itself, the disturbance being propagated through the mass of the earth.

Notwithstanding the lamentable destruction of life attendant upon the Krakatoa eruption, it has not been without valuable results to science. Apart from the investigations of sunsets, it led to the correction of many remarkable data in the transmission both of air-waves and water-waves, and with respect to the true nature of volcanic action. A committee was appointed by the Royal Society to collect information as to the eruption, and they have got together a vast amount of information which will doubtless be turned to good account in their report. I recently wrote to the chairman of the committee, Mr. G. J. Symonds, respecting the probable date at which this report might be expected, and he informs me that the members are still hard at work, and that it will be some months before any report can be issued, their labors being so heavy, and in many respects so difficult.

The earth disturbance which occurred in Essex, in the early part of 1884, also yielded some valuable data to science. In fact, were it not for the disasters which these and similar phenomena entail upon humanity, they would be welcomed as important matters for scientific investigation.

But the Java catastrophe, frightful though it undoubtedly was, is not without parallel in the annals of seismological disturbance. So few of us carry the facts of history in our heads, and so many of us are liable to have our imaginations unduly heightened by such tragic visitations, that we are apt to describe every extraordinary occurrence as unprecedented. It may therefore prove interesting, as well as instructive, if I reproduce from the *Science Monthly*, for January, 1884, a few facts and figures connected with the subject. Taking the number of lives sacrificed as affording the most concise indication of destructive effect of earthquakes in the past, the following approximate figures will help to reduce our most recent experiences to their proper proportions. Confining ourselves to the Christian era, we find that in the year 526 an earthquake in Italy destroyed about 120,000 lives. In 742, again, the greater part of Asia was severely shaken, more than 500 towns were wrecked, and an incalculable number of the inhabitants were killed. India, in 893, was the scene of an equally terrible shock, when, it is said, about 180,000 lives were lost. In 1040, Tabriz

(Persia) was completely demolished, and 50,000 of its inhabitants swallowed up in the ruins. In 1137, one of the earliest of the dreadful Sicilian earthquakes occurred, Catania being overthrown, and 15,000 persons killed. Some thirty-two years later (1169) a similar number perished in Sicily and Calabria. Almost exactly a century afterwards (1268), Cilicia, in Asia Minor, suffered a tremendous shaking, over 60,000 lives being sacrificed. An interval of nearly two centuries now elapsed, the next notable earthquake occurring in 1456, 40,000 of the people of Naples being destroyed by it. Lisbon, in 1531, was almost reduced to ruins, and about 30,000 of its citizens entombed. The following century was remarkable for several most destructive shocks. One occurred at Naples in 1629, when the destruction of life was set down at 70,000 souls; another took place in Russia (1667), the victims numbering 80,000; and the most terrible of all happened in Sicily (1593), more than 100,000 persons perishing.

The eighteenth century opens with the destruction of Yeddo, in Japan, and 200,000 of its inhabitants (1703). Only three years later, Naples suffered another of its many shocks, 15,000 perishing on this occasion. Algiers was the scene of several earthquakes in 1616; victims, 20,000. In 1727, Tabriz was again demolished, and 77,000 persons destroyed. The city of Pekin was leveled with the ground in 1731, about 100,000 Celestials being killed. In 1755 occurred the celebrated Lisbon earthquake, which seems to have marked a period of great seismological activity, shocks being frequent and severe in all the volcanic regions of the globe about that year. The total number of persons who perished between 1754 and 1756 must have been hundreds of thousands. A calm followed the storm, for the latter half of the century was comparatively free from disturbance; but 53,000 lives were destroyed in Japan in 1793, and shortly after, when the city of Quito, in Peru. was overthrown, 40,000 lives were lost. Coming nearer our own time, we find a destruction of 26,000 lives in Italy in 1805; 12,000 in Venezuela (1812); 20,000 at Aleppo (1822); 7,000 at Algiers (1825); 10,000 in St. Domingo (1842); 14,000 in Italy (1851); 10,000 in Persia (1853); 30,000 at Yeddo (1855); 15,000 in the Argentine Republic (1861); 10,000 in the Philippine Islands (1863); 25,000 in Central America (1868); and 14,000 in Chili (1875).

As I have already stated, these figures are only approximate, and, in fact, the whole record is somewhat barren, and affords but a poor idea of the destructive earthquakes of history. It has been computed that at least 7,000 shocks must have been experienced within historic times. Many of these have destroyed, not thousands merely, but tens of thousands of human beings; hence, the actual victims in all ages must be many, many millions. But the point here is, that the least of these eruptions utterly eclipses anything in the way of earth-dislodgement ever attempted by man.

Regretable, however, as are such occurrences as those to which I have just referred, they carry with them some consolation. They may even be said to have their bright side, inasmuch as they indicate that our earth still possesses life and vigor. In this respect the earth presents a marked contrast to the moon, some fine photographs of which I saw a short time since, and which presented it to the eye as the embodiment of sterility and desolation—a magnificent spherical clinker. Science has revealed to us the fact that the moon is absolutely dead; that it has not sufficient life left to ooze forth the tiniest mud volcano or to spurt out the feeblest geyser; that no throb ever reaches its surface, and that not the faintest rumble is ever echoed from its jagged mountain sides. No earthquake wave can ever sweep its face, for earthquakes there are things of the almost infinite past; the last drop of water quitted its valleys ages ago, and its very atmosphere has deserted it. Not even the 600° heat of the sun, which beats upon every part of the moon for a fortnight at a time, is able to quicken into life one atom of its mass, which, according to Professor Langley, has a temperature lower than that of melting ice. Everything goes to show that, at a time, its volcanic activity must have been of the most stupendous kind, far exceeding anything yet witnessed on this earth. But that has gone with its water and its atmosphere, and it is difficult to realize the fact that when we gaze upon its effulgent loveliness, we look upon what is, physically speaking, a charred and blackened corpse. That the earth has not yet lost its vigor is proved by the Java catastrophe and by subsequent similar minor manifestations. Moreover, we are told that so long as the old earth is equal to efforts of this kind, we need not fear its end; but that, when volcanoes and earthquakes cease from its face, the end may be within almost measurable distance. Much of its ocean water will have been absorbed by the underlying rocks, and the atmosphere may be rarer and less life-supporting than it is now, until at length, with the last atom of internal heat, the last drop of water and last particle of air, all life will have vanished and a dead earth will shine upon a dead moon.

I next proceed to notice the present advanced position of the science of engineering—which lays under contribution so many other sciences—and of our own profession, which puts that science into into practice. It is admitted on all hands to be a great science and a noble profession. It has compassed mighty purposes, has accomplished great ends, and, I cannot doubt, is destined to accomplish greater yet. Born, as it has been, of the present century, in fifty years the engineering profession has practically overrun the face of the whole earth, materially altering its physical appearance and condition. Seas have been united, countries have been divided, and continents have been spanned by the engineer, whilst lasting monuments of his power and skill dot the sea as well as the land. It is only repeating a truism to say that fifty years have produced great and marvelous changes in almost everything that pertains to life, thanks to the engineer. Even life itself is now due to conditions which did not exist fifty years ago. Where, at that time, disease was rife, and in many cases death inevitably stepped in and prematurely claimed its its prey, the sanitary engineer has successfully intervened, and has removed the cause and prevented the effect. Where, at that time, months were occupied in transmitting news to the other side of the globe, seconds now suffice, with the aid of the electrical engineer, to flash intelligence to and from the uttermost parts of the earth. Where, at that time, it took the lumbering old stage-coach days to accomplish a journey to the North at an average speed of ten miles an hour, the locomotive, thanks to the mechanical engineer, now takes us the same journey in a few hours at a speed of from fifty to sixty miles an hour; and, lastly, where, at that time, a few hundred copies of a newspaper were all that, at the best, could be produced in an hour, and those on detached sheets of paper, in the present day, thanks to Mr. Walter, of the *Times*, and also to the mechanical engineer, they are printed at the rate of thousands per hour, the paper being continuous and miles in length. In all this there is no idle boasting, it is but a simple statement of incontrovertible fact. And, if we stopped at a statement of fact, I might have nothing more to say upon the subject. But do we always so stop? Is there not rather an occasional tendency, both with writers and speakers, to magnify our times at the expense of former ages? I think there is. Not many years since, a prominent member of the profession expressed his regret at the non-existence of engineers 500 years ago. If he meant engineers as members of a recognized professional body, engineers of the present type, men who construct railways, manufacture steam-engines and machinery, and build ironclads and steel ships, his regret is intelligible. But even then, honestly speaking, he should have little cause for regret, inasmuch as the whole available surface of the earth might long since have been so completely engineered as to have left him no opportunity to have distinguished himself. He might then have wished that there had been no engineers 500 years ago. But, were there no engineers at that time? To take one instance only, one of the most important branches of mechanical engineering in the present day is that relating to the manufacture of artillery. It is a matter of history that cannon were first used in warfare at the battle of Cressy, which took place in 1346, and by the Moors in the defence of Algeziras, about the same period. Surely the manufacture of artillery was relatively of as great importance in the reign of Edward III. as in that of Queen Victoria, and those who carried on that manufacture are as much entitled to be considered engineers as those who manufacture the

100-ton guns of the present day. Perhaps more so, if we judge them by their light, and take into consideration the disadvantage at which they were placed as compared with their successors in the craft, who, with all their ingenuity and experience, and with all the materials and machinery at their command, manage to have a gun burst accidentally now and again. I know it may be urged that the guns of old were very small weapons. There is, however, one example still extant, of a more recent date, it is true, but of somewhat remarkable size and construction for the period at which it was produced. I refer to the celebrated Mons Meg, in Edinburgh Castle. This gun is said to have been manufactured at Mons, in Belgium, in 1476, whilst others hold that it was made in Galloway, and was used by James II. at the seige of Thrieve Castle, in 1455. It is, however, known to have been employed at the the seige of Dumbarton, in 1849, and at that of Norham Castle, in 1497. It burst when firing a royal salute in 1682. The gun is 13 ft. long by 20 in. in diameter, and is formed of longitudinal bars of wrought iron, encircled by hoops of the same material, its weight being five tons.

As a matter of fact, however, the "five hundred years ago" was merely an arbitrary definition of time on the speaker's part, for his remarks were intended to apply to the long past in general, and to imply that engineers were a race of men unknown to any time but the nineteenth century. The expression was, in fact, begotten of the spirit which, as I have observed, would fain magnify the present to the depreciation of the past. When we indulge in this view we surely forget the broken arches of the huge aqueducts and bridges which cross the Campagna, and which ought to remind us of the engineers whose names history has failed to preserve. Those who have forded rivers by the Roman paved paths, or who have driven for miles along the firm Prætorian Ways, which, 2,000 years ago, the conquerers of the world constructed for the march of their legions, might even doubt whether Telford, Macadam, and their successors have made any very great advance on their predecessors on the art of road-making. The Cloaca maxima was a sanitary institution which we have yet to imitate. The palaces and sewage arrangements of Nimroud, the hanging gardens of Nebuchadnezzar, the canal which Xerxes cut across the isthmus of Mount Athos, were, like the bridge of boats with which he spanned the Dardanelles, engineering works which we should all do well not to utterly ignore when we would exalt ourselves and our times in these respects. The men who reared the Pyramids, and who erected the monoliths of Egypt, possessed an art which died with them. It is, moreover, not a little singular that in the past, nations which are sometimes credited with having possessed no knowledge of science, have produced the most beautiful structures. The Mahommedans and the Hindoos, ages ago, without text-books, so far as we can learn, without scientific schools or rules to guide them, stumbled into the creation of those charming edifices which it is one of the privileges of Eastern travelers to see. That they were guided in some sort by scientific principles, we cannot doubt, and although we may not be able to discover them, are we justified in ignoring them? And how far back into the remote past can we peer in the vain hope of catching a glimpse of these workers at their early labors? Where is the page of history that discloses to us

"A race who carved the temple of the sun,
And mighty fanes from out the living rock;
Fanes which lay mouldering, o'erthrown by time,
While yet the pyramids were not."

We may exhaust tradition, and still find ourselves no nearer the time when such science as they had was flourishing at its best. The stupendous cavern temples of Nubia and upper Egypt proclaim an antiquity in the contemplation of which all tradition is lost sight of. The researches of some of our modern explorers lead to the conclusion that the most ancient buildings of the Thebaid, especially the great temple of Karnac, which had a circuit of a mile and a-half, are, to a large extent constructed of the materials of edifices themselves as ancient when they were thus dismantled as those which are now standing have become since their demolition. Thus we have come to be aware that the antiquity of a civilization so remote that tradition scarcely reaches to the latest epochs which its monuments illustrate, is at least doubled by the evidence of those monuments themselves.

And here I may refer to the fact that early in 1884, fresh proofs of the existence of an ancient civilization in Mexico were discovered in Sonora, about sixty miles south-east of the town of Madeleine, where some explorers found, in the heart of a virgin forest, a pyramid, which is 4,350 ft. round the base, and 750 ft. high, that is, nearly double the size of the great pyramid of Cheops. From the base to the summit there is a roadway on which vehicles can travel around the vast erection in a spiral. The outside walls are built of granite blocks carefully tooled and bedded. A little further off is a hillock, with hundreds of caverns or chambers cut in it, from 5 to 15 ft. wide and 10 to 15 ft. long. They have no windows, and are entered by the roof. The walls are covered with hieroglyphics and curious pictures, with the feet and hands of men. Stone utensils have also been found there. Who the builders of these ancient monuments were is still unsettled, but they probably belonged to the Mayos, who formerly inhabited Sonora, and were a different race to the Indians, having blue eyes, a white skin, and blonde hair.

The key-note to the favorable results of a comparison instituted between the works of the ancient and the modern engineer, as against the former, is undoubtedly scientific progress and development in its broadest and fullest sense. The bridges with which Robert Stephenson spanned the St. Lawrence and the Menai Straits are, as efforts of skill, infinitely beyond anything that Roman perseverance could accomplish. In like manner the simple contrivance by which George Stephenson succeeded in carrying the Liverpool and Manchester railway across Chat Moss, manifests a genius for a corresponding display of which, in the works of the ancients, we search in vain. Their works astonish us by their vastness, by their magnificence, and by the expenditure of brute force which must have accompanied their construction. Those of the moderns aim at introducing lightness and elegance of design, and economizing material and power, and they have to be examined in detail before their full merits are apparent. Take the magnificent bridge over the Firth of Forth, the works of which I recently had an opportunity of inspecting, and which twice span 1,700 ft. of sea at a stretch, at a height of 150 ft. above high-water level, with its cantilevers towering 200 ft. higher, and examine its details. In their minuteness and relative correctness with regard to each other and the whole structure, they are such as never could have been conceived by the ancients. Size and massiveness with them went hand in hand, resulting in an appearance of grandeur typified rather by the Egyptian style of architecture than by the modern Gothic. We should endeavor so to combine size with lightness, as to produce an appearance of elegance. Art and science, beauty and utility, when rightly understood, are never in conflict, and they can be as perfectly in agreement in a chimney stack in Manchester as in the beautiful Gothic of Milan Cathedral. The happy blending of true æsthetic principles with the more rigid and circumscribed requirements of utility in constructive art, cannot fail to produce what that gifted artist Von Schlegel has so beautifully described as "frozen music."

But if we reduce the design of Forth Bridge to first principles, what do we find? Simply that it is a development—a very grand one, it is true—of a rude kind of structure raised by the inhabitants of Thibet, Cashmere, and the mountains of India, consisting of beams projecting from piers. Each beam is made to project beyond the one that supports it, until the two sides approach sufficiently near to admit of a beam being laid across to connect them. Here we have a rude plan which has been converted into a scientific and beautiful method of construction by engineering science. The old semaphore system of signaling, which for years many of us were accustomed to see at work on the roof of the Admiralty at Whitehall and elsewhere, was of more imposing appearance than a thread of telegraph wire with a Morse sending instrument at one end and a Wheatstone automatic receiver at the other. But how incomparably superior to the former is the latter! Again, look at our glorious Nelson's ship, the *Victory*, in Portsmouth Harbor, and compare her with a modern torpedo-boat steaming past her at 22 knots an hour.* The contrast in size is striking, but the contrast in power in proportion to size is simply startling. The one would hardly make a cock-boat for the other, although whilst the ancient engine of war was changing her course but a few points the modern machine could come upon her, deliver its deadly message, and steam well clear of the vortex caused by the sinking three-decker.

I have said that the key-note to the advanced position of the present age is scientific progress, and I now desire to direct your attention to the circumstance that the principles involved in and underlying several of the most recent developments of science which constitute that progress were not unknown to some who lived in bygone ages. But although they appear to have been conversant with those principles, they lacked the power of giving practical effect to their knowledge. It is the possession of this power—this civilizing quality—and its legitimate utilization which have led to the remarkable developments of modern times. The scant records of the past have for the most part only brought down to us the theories of the ancients in such a vague form as to cause them to be passed by as the utterances of visionaries or the fantastic day-dreams of poets, unless, perchance, a train of thought should establish a connection between what may be regarded as the prophecy and its fulfillment. Take, for example, electrical telegraphy, which forms one of the practical adaptations of that latest-born daughter of modern science—electricity. Many of us are in the habit of unthinkingly associating with its invention the honored names of Cooke and Wheatstone, so prominent is their position in this connection, and so important the part they played. Great, however, as was their work, they only took up and perfected that of many others, their predecessors, whose labors led up to their victory. The electric telegraph had, properly speaking, no inventor; it grew up little by little, each inventor contributing his share towards its advancement. At least a score of names adorn the roll of fame in this respect. Commencing very nearly a century ago with those of Galvani and Volta, we encounter in our run down the stream of time, the names of Sömmering, Schweigger, Coxe, Romagnési, Oerstadt, Ampère, La Place, Fechner, Alexander, Sturgeon, von Cannstedt, Faraday, Morse, Gauss, Weber, and Steinheil, each of whom contributed successively a round in the ladder which was ascended by Cooke and Wheatstone. These latter, however, were the first to establish a telegraph for practical purposes on a comparatively large scale, and thus their names came into prominence, whilst those of Ampère, von Cannstedt, Steinheil, and others remain comparatively unknown in this immediate connection.

In referring to Galvani and Volta, I have looked back a hundred years to what appears to be the first conception of the idea of an electric telegraph. The means of attaining this end, however, may have been struggling for birth in reflective minds for many centuries past, for aught we know. In support of this, let me go back two centuries and a-half to the time of Galileo, who appears to have been fully aware of the importance of employing magnets for transmitting intelligence to a distance, although he did not see his way to the practical accomplishment of his idea. In one of the dialogues which he wrote in 1632 on the two great rival astronomical systems, he makes one of his myths, Sagredus, to say, "You remind me of one who offered to sell me a secret art, by which, through the attraction of a certain magnet needle, it would be possible to converse across a space of two or three thousand miles. I said to him that I would willingly become the purchaser, provided only that I might first make a trial of the art, and that it would be sufficient for the purpose if I were to place myself in one corner of the sofa, and he in the other. He replied that in so short a distance the action would be scarcely discernible; so I dismissed the fellow, and said that it was not convenient for me just then to travel into Egypt or Muscovy for the purpose of trying the experiment, but that if he chose to go there himself I would remain

* In the speed trials of two torpedo boats recently built by Messrs. Yarrow & Co, when the boats were loaded with 17 tons (representing the fighting trim), the speed obtained was 22¼ knots an hour, and when tried on the light water-line, 24 knots, which is equal to 27½ statute miles an hour, being the highest speed on record.

in Venice and attend to the rest."* Whether the idea originated with Galileo or with another who communicated it to him is not certain; but what seems perfectly clear is that in this dialogue we have the first absolutely defined conception of the electric telegraph. This interesting fact was pointed out to me some years since by an old friend, Mr. Richard Bellamy, a gentleman of considerable erudition. He also communicated it to Mr. Robert Sabine, who introduced it in the preface to his "History of the Electric Telegraph" in Weale's Rudimentary Series. Again, take the case of lightning conductors. Here we find that Franklin was probably anticipated in his discovery of lightning conduction. According to M. de Rochas, the ancient Etruscans understood the art of guiding lightning. Servius relates that in ancient times the priests ignited their sacrifices by lightning, and upon one occasion Tullius Hostilius was struck dead because he neglected the precautions laid down by Numa.

Turning to surgical science, let us take the circulation of the blood. The discovery of this wonderful principle was undoubtedly enunciated by Harvey in the early part of the seventeenth century, namely, in the year 1619. But I have read a very striking description of the circulation of the blood in a book which was written 2,600 years before Dr. Harvey's time. It is possible that Harvey may have read it too, and that, as a medical man, it may have suggested to his mind a research in the direction in which he eventually made his great discovery. It is also possible that, like thousands upon thousands of others, he may have merely read it, and have considered it a piece of poetic imagery bearing some occult meaning known only to the writer, and never further developed by him. In fact, like Wordsworth's Peter Bell—

> "A primrose by a river's brim
> A yellow primrose was to him,
> And it was nothing more."

I refer to that beautiful description of the decay, by reason of age, of man's natural powers, written by Solomon at the close of the Book of Ecclesiastes, in the year 977 B. C., or nearly three thousand years ago. He describes the dimming of the various faculties, under exceedingly poetical but equally appropriate and unmistakable symbols, and he goes on to say: "Or ever the silver chord be loosed, or the golden bowl be broken, or the pitcher be broken at the fountain, or the wheel broken at the cistern."* Here, then, we have the silver chord—the spinal marrow, the golden bowl—the heart, the pitcher at the fountain and the wheel at the cistern—both representative of the means by which the Easterns obtained and still do obtain water, and in conjunction with the golden bowl, clearly symbolizing the circulation of the blood.†

Another cognate matter is the comparatively recent discovery of those minute entities known as bacteria. I fear we can only call this a re-discovery, inasmuch as two centuries ago the celebrated naturalist, Leeuwenhoek, with wonderful skill, considering the very imperfect instruments of his time, anticipated modern physicists in this connection. The discovery of this circumstance is due to Professor E. Cohn, of the University of Breslau, who, a year ago, in a communication published in the *Allgemeine Handelsblatt*, recapitulates the substance of a correspondence of Leeuwenhoek with Francis Aston, of London, a member of the Royal Society. Leeuwenhoek, writing from Delft, in 1683, reports that among the *debris* of food remaining between his teeth he had discovered, with the aid of the microscope, living organisms moving with great activity. He distinguishes various kinds among them, which he describes so precisely that they are easily recognizable. One, which occurs least frequently, resembles a rod, the bacilus; others, twisting in curves, are bacteria; a third kind, creeping in snake fashion, is the vibrio ugula; another kind, of extreme minuteness, resembles a swarm of flies rolled up in a ball, and is evidently the micrococus; its movements cannot be traced with certainty. He says that this species seems to be made up of parallel threads varying

* "Galilei Systema Cosmicum," Dialogue I., Leyden edition, 1700.

* Ecclesiastes xii. 6.

† The "sakia," or Persian wheel, or the "natura," as it is called in some countries, is the great instrument of irrigation in the East. It consists of an endless chain formed of twigs, and strung with earthen pitchers. The chain passes over a wheel driven by oxen, and the pitchers raise the water from the well, and deliver it into a cistern.

in length, and remaining immovable, while other specks move in and out through the web. Leeuwenhoek marvels that these things could live in his mouth, notwithstanding his systematic habit of cleansing it. He instituted observations which showed that they were also to be found in the mouths of other persons. Some years later he could not discover any traces of those minute organisms, and he was lead to attribute their disappearance to the use of hot coffee. But shortly afterwards he rediscovered them as lively as ever. In September, 1692, he sent some sketches of them to the Royal Society. From this correspondence, it would seem that the knowledge concerning bacteria made no advance for nearly two centuries, but it clearly places Leeuwenhoek in the position of their original discoverer.

Quitting medical science, let me turn to that which relates to the production of our modern weapons of war and our most cunning devices for endeavoring to deprive our enemies of the pleasures of conquest. Here we have one who was both poet and seer, most distinctly foreshadowing the submarine traveling torpedo. This was Ben Jonson, who, in his play, "The Staple of News," wrote, in act. iii. scene 1, as follows:

THOMAS.

They write here one Cornelius' son,
Hath made the Hollanders an invisible eel
To swim the Haven at Dunkirk and sink all
The shipping there.

PENNYBOY.

But how is't done?

CYMBAL.

I'll show you, sir.
It's an automa, runs under water
With a snug nose, and has a nimble tail
Made like an augur, with which tail she wriggles
Betwixt the costs of a ship and sinks it straight.

PENNYBOY.

A most brave device
To murder their flat bottoms!

What, therefore, to the playgoers of Queen Elizabeth's time was the most palpable absurdity a poet's fancy could invent, is to us simply an accomplished scientific fact. In like manner, Dean Swift, 160 years ago, credited the astronomers of Laputa with the discovery of two satellites revolving about Mars, whilst the actual discovery of Mars' moons did not take place until about the year 1877.* These are, to say the least, curious coincidences, and however much Ben Jonson's "invisible eel" may have been the offspring of poetical fancy, and however little Swift's moons may owe their origin to astronomical knowledge, the fact remains that we have two distinct scientific forecasts which have been singularly verified in our own times. Even more remarkable than either of the foregoing is the poet William Drummond, of Hawthornden, who, 260 years since, did not simply shadow forth at the bidding of the muse what might then appear an absurdity or a quaint conceit, but in very precise language indicated some of the most important weapons of war used by the armies and navies of the civilized world in the present day. Looking through the records of the Patent Office some years since for information upon a cognate subject, I came across a specification entitled "The Letter of Master William Drummond for the Construction of Machines, Weapons, and Engines of War for Attack or Defense by Land or Sea, etc.," and dated September 29, 1626. In this remarkable document no fewer than sixteen inventions are apparently included, although only fifteen are indicated. The first is described as an instrument for cavalry use, by which a single man can be of no less avail in battle than five or six with the ordinary weapons. It is called a "box-pistoll" and a "muskett-box," and its effect is said to be at once terrible and rapid. This invention appears to answer to the repeating rifles and revolvers of our time. The second invention is described as a "shooting-spear," for a musketeer, and was probably a blade attached to the musket, as is the bayonet in the present day. The third invention is a number of musket barrels fastened together, and called a "lightning chariot," which would appear to be the prototype of the mitrailleur and Gatling gun of modern warfare.

* "They have likewise discovered two lesser stars, or satellites, which revolve about Mars, whereof the innermost is distant from the center of the primary planet exactly three of his diameters, and the outermost five; the former revolves in the space of two hours, and the latter in twenty-one and an half; so that the squares of their periodical times are very near in the same proportion with the cubes of their distance from the center of Mars, which evidently shows them to be governed by the same law of gravitation that influences the other heavenly bodies."—*A Voyage to Laputa, etc.*, edit, 1755.

The fourth invention is described as one from which three, four, or even five balls were to be fired in the same time as a single ball, and from the name given to this appliance of "open ordinance" it would seem that modern breechloading artillery was foreshadowed.

The sixth and seventh inventions relate to guns, one of which is called a "flatscourer," and the other a "cutter,' the inference being that the use of chain shot was here intended. The seventh invention is a movable fort or turret for soldiers. The eighth invention is omitted from the original document, nor is there any clue as to its nature. Now it is just possible that this missing invention may have been the one imported by Ben Jonson into his play, and I will give you my reasons for thinking so. I find that Jonson visited Drummond at Hawthornden in the spring of 1619, and the latter may then have communicated his ideas in this respect to the former. Jonson's wit would readily transform the more sober notion of Drummond into satire, and this might prevent Drummond with his more sensitive nature from making public the original of Jonson's ludicrous automaton. As tending somewhat to prove the correctness of my assumption, I would remark that the ninth is in some sort a cognate invention with Jonson's "automa," inasmuch as it is described as "a new sort of ship which can enter ports of any sort, even barricaded by powerful chains, bars, or engines, and can destroy whole ships by fire or forcibly capture them." "The ship," continues the specification, "from its immense and really terrible effect, and its tremendous destruction of ports and ships, deserves to be called 'Leviathan.'" This would appear to embody the idea of our modern ships of the ram class.

Here Drummond appears to have exhausted his stock of invention as regards the arts of war, and he turns his attention to those of peace, for the tenth item is an instrument for measuring the speed of the wind, or of a ship, in fact, an anemometer and a log combined. The eleventh invention is a "sea postilion," which in some respects answers to our little steam launches. The twelfth invention is worthy of note; it is called a "lenth-compas, by which the distance of a voyage may be exactly calculated, and the different longitudes, either at sea or on the nearest shore, determined." Now here we apparently have the first suggestion of a means of discovering the longitude of ships at sea. The patent, as I have said, is dated 1636, and it was not until 1674 that a Frenchman—St. Pierre—submitted to Charles II. a method of effecting this object. The proposition was referred to a committee of astronomers, of which John Flamsteed—the first astronomer royal of England—was a member. Flamsteed drew attention to the incorrectness of the lunar tables by which the position of the moon amongst the fixed stars was to be calculated. Struck by the deficiency, the monarch is said to have at once founded the Observatory at Greenwich, which was called Flamsteed House. The king appointed Flamsteed to the post of astronomer royal, at a salary of £100 per annum. It does not appear that previously to this any attempt had ever been made to determine the longitude of a ship while at sea. To return to Drummond, I have only to notice that his thirteenth invention was a still for rendering salt water potable, whilst the fourteenth and fifteenth have reference respectively to burning-glasses and telescopes, or "lynxes eyes," as he calls them. In the sixteenth and last invention Master Drummond falls foul of that *pons asinorum* of inventors of all times—perpetual motion—for he describes it as "a machine producing perpetual motion from a natural cause, and one incapable of fatigue, by the employment of whose aid a variety of mechanical operations may obtain motive power, and it is called 'momet.'" Such is the poet's remarkable list of inventions, which I need hardly say embraces a far greater variety of subjects than could be coaxed into a single patent in the present day, especially under the new law. The inventions are not in any case described in detail, nor does Drummond illustrate them, a course which some inventors of our own time would like to be permitted to pursue. Neither am I aware of Drummond having carried any of his inventions into practical effect. Of course, breechloading arms are by no means so modern an invention as is generally supposed, as the relics in the Tower of London show. Possibly some of these might be traced to Drummond's patent, although this is very problematical. Be this as it may, there is no question that those of his inventions which relate to the arts of war do certainly foreshadow many of those at present in prominent use, and which are regarded more or less as distinct creations of our own times. As it may occur to some that they have come across this somewhat singular disclosure respecting Drummond before, I may here mention that the matter formed the subject of an article from my pen which appeared in the leading journal some nine years since.*

Before quitting the region of prophecy and fulfillment, I would observe that England's greatest poet—Shakespeare—appears to have placed himself in the same category as Jonson and Drummond. In the second scene of the fourth act of "Troilus and Cressida," Shakespeare makes Cressida say—

> "But the strong base and building of my love
> Is as the very center of the earth,
> Drawing all things to it."

To my mind the poet here most clearly anticipates Sir Isaac Newton's great discovery of gravitation.

I have taken you back with me a long way into the past, not merely to prehistoric times, but I have even exhausted tradition. It must not, however, be assumed from this that I live in the past. I live in the present, and for the future. I obey the poet's behest, which is to

> "Look back upon the past, and by the lights
> Which now are thine, onwards towards the future."

Let us see, then what the facts I have adduced teach us. I think they show us that what was aforetime spoken hieroglyphically and in fable is now being spoken plainly. In fact, the idealism, the imagination of a bygone age has in more instances than one become transformed into a reality in the present one. The dream of the poet, and the inchoate indefinite idea of the sage of antiquity have become materialized, and produce the daily bread of the artisan. That which was once purely spiritualistic, and which formed one of the highest elements of fiction—communication and identity of thought without sense of distance—has become strangely realistic, and is inextricably interwoven with the web of ordinary everyday life. It is, however, one thing to have a vision, but quite another to be able to give it form; one thing to conceive, but quite another to invest the conception with practical existence. But in the past, when knowledge was power of an oppressive and tyrannical character, a veil of impenetrable mystery was drawn around the early germinations of science by her bigoted votaries. The pursuit of knowledge was only permitted to the few, whilst the mass wondered ignorantly on in mingled terror and admiration. Hence it is reasonable to suppose that there were in former ages developments of science which ran parallel with some of our own—in fact, I have to some extent shown this to have been so—but they were most jealously guarded, and have been buried with overthrown nations. We may also learn a lesson of patience and unresting, but not restless, perseverance in our work. Great results are not achieved in a day, or, as Smiles appropriately puts it, "great inventions are not brought forth at a heat." They are begun by one, improved by another, and perfected by a whole host of successors.

The facts I have brought before you also point to the moral and material progress of the world. "The bee that hummed its busy hour through the bowers of Paradise," wrote Sydney Smith, "fashioned its hexagon with the same mathematical precision which it does now and here. Six thousand years have added nothing to the sagacity of the horse or the intelligence of the dog." But how widely different with man! He commences as a fire-worshiper and rises to a Newton, a Faraday, a Stephenson, a Siemens. Tempts the river in a few fragments of bark lashed together with thongs of raw hides, and crosses the Atlantic in an iron steamship of 22,500 tons burthen.† Burrows in the earth, and then builds a city with four millions and a-half of inhabitants. Sticks a dried reed in a lump of fat to light his mud hut, and carbonizes 2,200,659 tons of coal per annum to illuminate London.‡ Takes weeks to send mes-

* *Times*, November 29, 1877.

† The *Great Eastern*.

‡ During the year 1884 the Chartered Gas Company carbonized 1,568,821 tons of coal; the South Metropolitan Gas Company 457,637 tons, and the Commercial Gas Company 174,201 tons; total, 2,200,659 tons.

sages on sticks to Montezuma, from the coast, and at last reports in London the details of a battle fought in the Soudan the same morning. Slays his foe with a sling and a pebble chosen from the brook, and meets the enemy with a machine-gun firing 600 rounds a minute by means of its own recoil.* Lays seige to a city with a balista, throwing a fragment of rock, and finally attacks a fort with a gun weighing 110 tons, projecting a steel shell of 1,800 lbs., with a charge of 900 lbs. of gunpowder. The axe-head that floated for a few seconds on the Jordan three thousand years ago, when "the iron did swim," was a miracle indeed; but what of the hundred of thousands of tons of iron that are now continually swimming over our seas in masses some thousands of tons each?

These are extremes, and they stand very wide apart. But they are to-day the beginnings and the endings of science, and thus stated, they bring out in bold relief the contour lines of progress. But they are the endings of science as regards the present only. They are by no means final, or science never stands still. They are but the landmarks of our times, which, as Emerson puts it, are "trivial to the dull, tokens of noble and majestic agents to the wise; the receptacle in which the past leaves it history; the quarry out of which the genius of to-day is building up the future."

* The Maxim gun.

The progress of science, however, is very far indeed from being measured or measurable by its material achievements. It has done infinitely more than merely give us railways, telegraphs, arms of precision, and other practical applications of its discoveries. What it has further done I cannot express better than in the words of a recent anonymous writer, who says: "It has given to the human race, for the first time, standards of truth which are at once absolute and accessible, and has thus caused a knowledge of truth, of its tests and evidences, and an engrossing love it, to become the chief mental characteristics of those who are really engaged in it. Great as have been the material rewards of science, the moral rewards will be greater still." The opportunities of scientific education, which are daily increasing in our midst, must hasten the coming of the time when these moral rewards shall be within the reach of all who will stretch forth the hand to grasp them.

TRIPLE EXPANSION ENGINES.

From "The Engineer."

The literature of the triple expansion engine is at present extremely limited. Indeed, all that has been written on the subject might be put within the covers of a very small volume. It is comprised in certain papers read before engineering societies, and articles which have appeared from time to time in our own and other technical journals. It is with the more pleasure, consequently, that we have read a pamphlet, "Etude sur les Machines Compound à Triple Expansion," by Mons. Maurice Demoulin, and published by Messrs. Baudry & Co., Rue des Saintes-Pères, Paris. The position held by Mons. Demoulin with the Société Ateliers et Chantiers de la Loire, has enabled him to write with a competent knowledge of his subject, and we can strongly recommend the work to those of our readers interested in steam navigation. It is not our intention to review the pamphlet here, but it contains some statements the accuracy of which seems to us to be open to question. These statements have not, we think, originated with Mons. Demoulin, and his responsibility for them is perhaps one of adoption only.

It is commonly assumed that one of the reasons, if not the reason, why the compound engine is more economical than the simple engine, is that the range of temperature in the cylinders is smaller. As Mons. Demoulin puts it, the condensing power of the cylinders of a compound engine is less than that of the cylinder of a simple engine; and he gives a table illustrating this theory by a practical example. No doubt to a certain extent he is right. He assumes an initial pressure of 127 lbs. per square inch, a back pressure of 4 lbs., and a total range of expansion 10. He then states the case for three different engines of the same power. The first has a single cylinder, with a stroke of 1 meter, and a diameter of 1.5 meter; the second is a compound engine, with a stroke of 1 meter, a high-pressure .75 meter, and a low-pressure cylinder 1.5 meter in diameter; and lastly, a triple expansion engine, with a stroke of 1 meter, and cylinders .61, .96, and 1.5 meter diameter respectively. He multiplies the surface in each cylinder by the range of temperature in it, and adds all the products together, getting as the coefficient of condensation in the single-cylinder engine, 895.98, in the double-cylinder 686,34, and in the triple expansion 585.06, showing an advantage of 15 per cent. possessed by the double over the single-cylinder, and 34 per cent. possessed by the triple-cylinder over the first. This calculation is based on the amount of surface in each cyliner. The large cylinder is the same in all the engines. Its diameter is 59 inches; its condensing surface, allowing for clearance, will be 7,412 square inches for the cylinder walls, and 10,932 square inches for two piston faces and two covers, or 127.3 square feet. We have made no allowance for passages or piston-rods; yet Mons. Demoulin makes the surface only 8.22 square meters, or 88.5 square feet. Multiplying 127.3 square feet by the range of temperature due to a fall of pressure from 127 lbs. to 4 lbs., we have 24,441, in round numbers, as the coefficient of condensation of the single-cylinder engine. In the triple expansion engine the high-pressure cylinder has a surface calculated in the same way of 33.5 square feet, but Mons. Demoulin makes the surface only 26.88 feet. The intermediate cylinder has by our calculations a surface of 64 square feet; by Mons. Demoulin's, 46 square feet. He assumes the fall in pressure in the first cylinder to be from 127 to 50 lbs. The range of temperature is 64 degrees. The fall in the intermediate cylinder he assumes at 50 lbs. to 21 lbs., or 51 degrees, and for the low-pressure cylinder 21 lbs. to 4 lbs., or 77 degrees.

Multiplying the areas by the ranges of temperature, we have for the high-pressure cylinder $33.5 \times 65 = 2177$ as its coefficient of condensation. For the intermediate cylinder we have $64 \times 51 = 3,264$, and for the low-pressure $127.3 \times 77 = 9,802$. Summing up, we have 15,243 as the coefficient of condensation in the triple expansion engine, a result different from that given by Mons. Demoulin. It seems probable that he has in his calculations forgotten to include the surfaces of the pistons, which are quite as potent for condensing purposes as the surfaces of the cylinders. The influence of the passages is also very considerable, especially in some types of engine, in which the ports are very long; the high-pressure slide being some way from the cylinder, as, for example, in the engines of the Arabian, an excellent lithograph of which is given by Mons. Demoulin. Indeed, the proportion borne by port and valve surface to that of the cylinder is often very large, and ought not to be neglected. His calculation is also to some extent invalidated by the fact that he has in all cases taken the terminal pressure in one cylinder as the initial pressure in the next, which it never can be. The range of temperature in each cylinder will therefore be less than he has made it, so that he has sacrificed a point in his own favor, balanced, perhaps, by the circumstance that inasmuch as there is a continual rise and fall of temperature in the intermediate receiver or receivers, there is probably condensation and re-evaporation going on there, of which he has taken no notice.

All calculations of this kind are, however, vitiated by the remarkable fact that condensation in the high pressure cylinder of a triple expansion engine is known to be not less than that which takes place in the single-cylinder engine. It is not, perhaps, easy to explain the cause. It is possible, however, that the whole body of steam comes more freely in contact with the metal of the small than can be the case with a large cylinder. It has, at all event, long been known that the efficiency of a jacket augments as the diameter of the cylinder decreases, and this can only be because cylinder condensation diminishes as the diameter of the cylinder is increased. It matters nothing, be it understood, how initial condensation takes place, so long as it does take place. That is to say, the loss of efficiency would be the same whether part of the condensation took place in each cylinder of a triple engine or all in one. The boiler does not know what becomes of the steam, and if, as is sometimes the case, over 40 per cent. of the whole is condensed in the high-pressure cylinder, the loss falls directly on the boiler, and will be the same as though 40 per cent. had been condensed in a single-cylinder engine. But it is very well known that, be the condensation what it may, the resulting water does not to the end remain water in the engine. A portion, at all events, is sure to be re-evaporated. The economy of the compound engine depends on the fact that the resulting steam is used expansively in the second, or in the second and third cylinders. Mons. Demoulin recognizes this himself, for he says:—"Les moteurs à detente multiple doivent leur supériorité économique, en partie aux causes que nous avons signalées, en partie á un fait tres important qui, jusqú'á nos jour, a echappé á la plupart des savants et des ingénieurs, et qui consiste en ce *la vapeur condensee au petit cylindre agit, apres sa réévaporation, sur les pistons des cylindres d'expansion pendant tout la course et avec une détente qui lui est propre*, puisque l'introduction est limitée à une fraction de la course. Avec la machine monocylindre, au contraire, la vapeur produite par la réévaporation pendant l'expansion, dans le cylindre, de l'eau de condensation, *ne se détand, mais agitsimplement comme si elle était fournée, a pleine admission par une chaudiere distincte*, a la pression correspondant; on perd ainsi un notable quantité de calories." The italics are Mons. Demoulin's. We believe that we were the first to place this fact before English readers, though it was about the same time announced in the United States. In one word, the compound engine is more economical than the simple engine working with the same range of temperature $T-t$, because in the former the principle of expansion is more fully carried out.

LIQUID FUEL.

From "Nautical Magazine."

There are not wanting signs that, in the immediate future, "liquid fuel" will have established a position of importance, as one of the products by which steam can be easily and economically generated.

Shipowners should be among the first to welcome such a result, nor should they be slow to allow it a fair trial. So many are the advantages to be derived from its use, which we partially pointed out in our last article on the subject, that it scarcely can fail in most cases to give satisfaction. The entire absence of smoke is not one of the least advantages.

There are several patent arrangements in existence for burning "liquid fuel," among them that of Mr. Percy F. Tarbutt, which has been fitted to the late steamship Himalaya, now renamed the steamship Marahu, for which extraordinarily good results are claimed; also Admiral Selwyn's, which was some time ago tried experimentally by the dockyard authorities, but, so far as we can learn, not with the most satisfactory results, although at the present time, at Middle Scotland Yard, London, on a piece of waste ground, the Admiral has had a marine boiler fitted up to burn "liquid fuel" by his arrangement, which all interested can see for themselves; and Colonel Sadler's patent burner, which has proved in the short time it has been in use to be more than a mere experimental success. This last-mentioned method of burning "fluid fuel" is already, and has been for months, in daily use for generating steam at a number of manufactories and shipyards, and among the firms who have adopted it are Messrs. Orr-Ewing's, the large firm of dyers at Alexandra, in Dumbartonshire; the Gartsherrie Ironworks (where it is also used for smelting iron); Messrs. Raylton, Dixon & Co.'s shipbuilders, Middlesborough; the North of Ireland Chemical Company, and also at Messrs. Sadler &

Co.'s Chemical Works, at Ulverston, Portsmouth, Stockton-on-Tees, and Carlton. At the various chemical works mentioned, creosote oil, a waste product of the distillation of tar, is used as fuel for the furnaces of the retorts used in distilling tar. The production of this oil is not confined to one firm; and in addition to the Chemical Company in Ireland we know that the Walkinshaw Oil Company at Paisley produce "liquid fuel," and are supplying it to manufacturers and others at 20s. to 25s. per ton, according to the place of delivery, and they likewise use this fuel for their own purposes.

There may be in the minds of some, doubts as to the possibility of arriving at such a saving in the weight of the fuel necessary to be carried by a steamer as 50 per cent., but when all the circumstances of the case are considered, it will be seen that this is a fairly reasonable result to be anticipated by the use of "liquid fuel" of an approved character.

Although "creosote oil" has not, so far as we can learn, been subjected to experiments for the purpose of ascertaining the exact component parts of the heating agents, yet it is believed that they are substantially the same as good petroleum, and, from the analysis of eminent chemists, we find that various solid and fluid fuels give the following percentages by weight of heating agents:

	C	H	O	CO	CH_4	C_2H_4
Anthracite coal	87.7	3.3	3.2			
Bituminous	80.8	5.0	8.2			
Petroleum	84.4	13.1	1.5			
Coal gas		6.5		14.3	52.4	14.8
Generator gas		1.98		35.5	1.46	
Water gas		6.3	0.6	87.8	1.2	

By Dulong's formula—

$$H = 14{,}500\,C + 62{,}000\,(H - \tfrac{O}{8}),$$

we obtain for the combustion of one pound of

Anthracite	14,500	units of heat.
Bituminous	14,200	"
Petroleum	20,300	"
Coal gas	20,200	"
Generator gas	3,100	"
Water gas	8,500	"

According to another authority

	Units of heat.
A pound of coal gives	14,000
" petroleum, light oil, gives	22,628
" " heavy, gives	19,440
" " refined, gives	19,260
" Pennsylvanian, crude, heavy, gives	19,210

From these results we readily find the comparative evaporative power, which is as follows:

	Pounds of water evaporated from 212° Fahr.
Coal varying from	14.5 to 15.02
Petroleum "	19.95 to 23.44
Coal gas "	20.87
Generator gas "	3.11
Water gas "	8.7

and from what has already been stated, it may be fairly assumed that 1 lb. of creosote oil would have theoretically the power to evaporate 21.5 lbs. of water.

Experimental results with solid and liquid fuels show that there is, however, a wide difference in their efficiency, coal being for instance variously estimated to have from forty to sixty per cent., while it is generally admitted "liquid fuel" gives ninety per cent of efficiency. This great difference is largely due to the fact that the more efficient fuels require for combustion very little air, while for coal fully twice the theoretical quantity must be admitted to the furnaces to dilute the products of combustion; there are also great losses by stoking, in opening the firedoors to apply green fuel, damping down, &c. Basing our results on the percentages of efficiency just stated, and confining ourselves to the two most important liquid fuels, we find the

Actual evaporation from 212° Fahr. per pound of fuel in—

	lbs.	lbs.
Coal varies from	5.8 to	9.0
Petroleum "	17.96 to	21.1
and Creosote oil, say		19.4

which shows a possible saving in weight with using creosote oil in the place of coal of from 53½ per cent. to 70 per cent.

Now, in actual practice it has been found that, with land boilers of the Lancashire type, one pound of creosote oil gives as efficient results as 2.33 pounds of coal, which is equal to a saving of 57.08 per cent. This result was obtained at Messrs. Sadler & Co.'s works, Middlebro'; but almost the same has been obtained by Messrs. Backhouse & Dixon, shipbuilders, who, despite the fact they bought their coals at 7s. 6d. a ton, find that liquid fuel at 25s. per ton is somewhat cheaper, owing to the saving of labor, in moving the coal, firing and cleaning furnaces, and removing ashes. We have recently had an opportunity of seeing a 30-ft. Lancashire boiler fired with "creosote oil," and it gave an exceedingly bright flame, and practically emitted no smoke, so as to lead to the conclusion that it might even be used with advantage, at least in some cases, for illuminating purposes.

In our last article we mentioned that the steamship Cobden had been fitted with Colonel Sadler's patent burner, but this is not the first vessel that has made a trial of this mode of burning "creosote oil." Some time ago the steamship Emmanuel had the furnaces of her boilers temporarily adapted for the consumption of liquid fuel, but as it was only an experiment, as in the steamship Himalaya, provision was left for replacing the fire-bars usually in the furnaces. Loose bricks were merely laid in the bottom of the furnace, and even with this rough and ready adaptation of the boiler, the liquid fuel gave every satisfaction on a voyage to the Mediterranean and back to the United Kingdom. In the steamship Cobden the arrangement of the furnaces is of a permanent character, no provision being made for using coal in the furnaces of the boiler that has been adapted for liquid fuel. The steamship Cobden's boilers are about 12 ft. in diameter, and about 10 ft. long, and owing to their comparative shortness it has been considered necessary to extend the furnaces about three feet beyond the front of the boiler. Inside the furnace there is a ring of brickwork of varying thickness about six feet long, and at the end there is a baffle or screen, with perforations of about three inches square. The doors of the furnace are in two halves to admit of the introduction of the burner and piping in connection with it. A small steam-pipe is led to the burner, and on lighting the fire the steam is first turned on, and then the oil which is led from tanks (as we will describe further on) is allowed to flow down a funnel into the burner, where it mingles with the steam. Then a lighted torch is applied to the outlet of the burner, which, by the way, is on a similar principle to Giffard's injector, and the only close attention required is at the lighting of the fire, as until the brickwork has become heated, a torch must be kept at the mouth of the burner. This is, however, only the work of a few minutes, for if a boiler were fitted with means of circulating the water, steam could be raised in about twenty minutes.

The tanks for storing the oil are, in the case of the steamship Cobden, placed under the hurricane deck and on the main deck, abaft the stokehole grating. These tanks are connected together with piping, which is led down to a small indicating tank in the stoke hole. A gauge on this tank shows whether there is oil sufficient immediately available for the furnaces, if not, a cock is turned on deck, which permits of a further supply descending to the stoke-hole. Creosote oil being liable to crystallize at a temperature below 120° Fahrenheit, it is necessary to adopt precautionary methods for removing any crystals, grit, or other deposit to prevent the pipes choking. When the oil is being filled into the tanks on deck, it is passed through a sieve, and a further precaution is taken in the stoke-hole tank by having a strum box fitted in it, through which the supply from the deck tanks has to pass. The engineer of the steamship Cobden speaks very favorably of the whole arrangement, and stated that there was such an absence of smoke as to render a funnel almost a superfluity. The boiler has recently had a damper fitted to further check the great draught arising from the action of the jet of steam, and with one furnace only burning, it is kept in reality shut. Although a slight deposit of carbon is in the course of time deposited on the burner, during the seven voyages this vessel has made since the burners were fitted, not one has choked, and what little carbon has been deposited has been as readily removed.

The results obtained by burning creosote oil in the furnaces of the steamship Cobden's boiler have scarcely been so satisfactory from an economical point of view as in the case of boilers on land, but this is largely due to the fact that about half of the length of the furnaces project outside the boiler, resulting in considerable loss of heat by radiation. In longer boilers, where it would be practicable to have the furnace entirely inside the boiler, without doubt the result would be a saving of fuel of at least 50 per cent. Boilers specially constructed with a view to burning liquid fuel, should naturally be expected to give better results than old boilers adapted, and as experience in using oil fuels increases, even greater efficiency may be fairly anticipated.

At present, there is being fitted up with tanks for the oil trade between the Black Sea and Antwerp, the steamer Fergusons, which vessel has been chartered for a lengthy period for the purpose of carrying oil. The furnaces of the boilers are being fitted with Colonel Sadler's patent burner, but in this case it is at present only intended to use "oil fuel" as an auxiliary to coal—only the leakages from the cargo being used—although it is very probable that after a time arrangements will be made to burn liquid fuel entirely in the place of coal. The alterations to this steamer are being carried out by Messrs. Westgarth, English & Co., engineers. Middlesbro', while the fitting of arrangements for burning the "oil" in the steamship Cobden were entrusted to the well-known firm of engineers, Messrs. Blair & Co. (Limited), at Stockton-on-Tees.

On the Clyde, as has already been noticed, progress is being made in the use of oil fuel for generating steam in boilers, etc., among manufacturers and others, and recently the steamship Fern, a passenger steamer belonging to the Laird line, trading between Glasgow and Ireland, has had fitted to the boiler furnace, arrangements for burning "liquid fuel," and the results of several trials have displayed many of the advantages to be obtained by its use. It is also stated that the Walkinshaw Oil Company have asked the Clyde Trust to place at their disposal one of their "Clutha" ferry steamers, for the purpose of further showing the practicability and special suitability of oil fuel to passenger steamers. We are, however, persuaded that the full advantage of adopting fluid fuel will never be obtained until steamers going on long voyages, such as to Australia and China, are allowed to give it a trial. Especially for steamers who remain away from the United Kingdom for a year or two, trading in the East, should this fuel be found to be economical; as hundreds of tons of oil could be taken from the United Kingdom in their ballast tanks.

In America, in our last article, we remarked that liquid fuel as yet does not appear to have secured for itself "a permanent position as an economical fuel." Although petroleum is relatively cheap, yet for land purposes there are wanting some of the advantages obtained by its use for steam vessels, and coal is to be obtained in most districts of America at a reasonable rate, while petroleum, in some districts, reaches a price of about £5 per ton. Recently there has been a revival in the use of petroleum, but in this instance as fuel for the boilers of steamers. Owing to the large deposits of petroleum discovered on the Pacific Coast, the price there for oil fuel is less than £2 per ton, while coal is about £1 10s. Evidently here is an instance where economy at once demands the adoption of the more modern product, and the Central Pacific Railway Company have not been slow to take advantage of the more economical fuel. All their steam vessels at Oaklands, their western terminus, are now burning petroleum or its waste products; and in the case of one of their vessels, which has been longest adapted to burn oil fuel, in five months of this year it was found there was a saving of fifty-six per cent. for fuel, as compared with the corresponding five months of last year when coal was burned.

Some hardware manufacturers in Birmingham, England, are taking pains to make themselves familiar with the goods of continental manufacturers which come into competition with their own productions. Such a course is worthy of wide imitation, and is the surest road to successful combating of the threatened difficulty without recourse to restrictive tariffs. That in many branches we are behind our continental competitors in the adoption of machine production, which accounts for much of the continental cheapness, is undeniable; nor does it follow of necessity that the continentals are making a profit upon all the trade which they are seeking to do with this country. Trustworthy evidence upon this point is much needed.

TIMBER.

From "The Building News."

Mr. Thomas Blashill, F. R. I. B. A., who took as his subject "Timber: Its Growth, Seasoning and Preparation for Use," said: Plants recognized as trees belong to two different classes—the endogenous specimens, in which the fresh matter is added in the center, and the exogenous trees, in which the increase was by coats of wood added on the outside of the stem. In the former class, of which palms were the best recognized illustrations, the center of the tree consists of but pith, with an outer husk of bark. In the latter class, to which all our timber trees belong, we easily recognize three distinct parts—the bark, the wood, and the pith. Now, consider the growth of one of the latter class of trees as it appeared, say, half a century after it sprouted from a seed. The pith, at first a very distinct rod of white, spongy substance, afterwards dried and shrunk, becoming partially dead. Outside was the wood in fifty rings, usually very easy to count. All, except a few of the outer rings, were comparatively hard and dry, of darker color than the rest, and practically dead also, because they had ceased to take part in the life of the tree. This was the heart now. Outside it was one, perhaps three or four—perhaps two—rings of softer wood, full of sap, light in color, and, when carefully examined, considerably alive. Outside this sapwood was the bark: first the inner bark—white, moist, living, consisting of many thin layers or rays. Finally, there was the outer bark, consisting of a layer containing such coloring matter as the stem might have, and an outer layer resembling the central pith; this might be thin, as in the birch, or thick, as in the cork oak. The lecturer next proceeded to inquire into the manner of growth of a tree, with reference to the eventual effect of external and internal influences on the timber. Having alluded to the rise of the sap, the lecturer showed that this fed the thin layer between the inner bark and the last annular ring, so thickening it that, tightly as the bark enclosed the stem, it had to yield to the pressure. The bark consisted of reticulated fibers, which allowed of a certain amount of expansion, but the internal pressure also caused it to crack and peel in places in various ways according to the thickness of the tree. It should be remembered that the stem was never quite correct, as the rings were never of the same thickness all around. They were generally thickest on the sunny side of the tree. If all the branches and roots were on one side of the tree, as when it stood at the edge of a wood, all the rings were enormously thickened on that side. In the Museum at Kew there was a section of a fir tree which measured from pith to bark on one side 13 in., and on the other side 4 ft., each ring being, on an average, four times thicker on the one side than on the other. The rings differed from each other also in thickness. As the tree developed fresh branches, the rings tended to get thicker. In a good season they were thickest, in a bad season decidedly thinner, so that a growing tree was a self-acting register of the weather, as far as regarded its suitability for vegetation. In fact, we might count the rings back for centuries, and gain some generalization of the average summer weather of each year. When the sapwood was a few years old—say, from three to four years in chestnut, seven years and upwards in oak—the sap ceased to flow in it, and it changed in a season to heartwood, but not quite uniformly. Two or three rings would often be turned to heartwood on the sunny side of the tree, while they remained full of sap on the opposite side. The heartwood became solid, and its pores were filled up with any gums or resins that the particular kind of tree produced. The heartwood underwent no further change until the tree grew old, when it was the first part of the wood to decay. The sapwood kept up a sort of growth within itself as long as it existed in that condition. Another very important feature in the wood of all timber trees was that they produced plates of woody fiber that in the young plant connected the bark with the pith. These were known as "medullary plates." They were not visible to the naked eye, except in oak, beech, and some few other trees. They were very conspicuous in the end grain of oak. As the trunk increased in size, fresh medullary plates start up midway between the older ones, and are kept growing at the junction of the sapwood and bark, and extend both towards the center and outer surface. The plates were only a few inches in depth up and down, but between them fresh ones started out, so that they overlapped each other. When we see them in the end grain, showing as bright, fine lines, they were termed "medullary rays"; when seen sidewise in a split log, they were known as the "flower," or silver grain. Having exhibited specimens of oaks showing these plates, the lecturer referred to the beauty they imparted to this wood, and mentioned that the plates could not be traced in the Spanish chestnut, ash, or elm. The medullary plates were not only ornamental, but very serviceable in oak timber. They added to the strength of the wood across the grain, so that the pins of oak tennons would not draw out. They were harder than the rest of the wood. In an oak slab which had seen many years' rough wear, say the sill in the ticket window of a railway station, on which the booking clerk dashed down his change, the silver grain stood up in ridges above the wood of the annual rings. They resisted shrinkage, decay, and worms, which would only bore through them in order to get at the softer wood beyond. A few things showed how the wood grew by annual layers. Let them suppose that three branches were removed from a tree, one being taken off close to the trunk, the second cut off with a few inches of projection, and the third left long enough to produce twigs and leaves. The new wood would, in a few weeks, grow over the first, leaving a wound in the wood called a bandgall. The second would have become a dead stump, owing to the absence of leaves, and would next be enclosed by the new wood. The third would continue alive, because it had been able to develop leaves. Iron spikes driven into trees were often grown over. He exhibited a specimen of English walnut wood, lent him by Messrs. Broadwood, in which the head of a long iron, used to fasten wire fencing, had been covered over with 3 in. of new wood. For all uses of any importance, timber should be taken from the heartwood of a sound, well-grown tree. The grain should be close and firm, and should sound well when struck. The annual rings should be of even thickness and the grain straight. It should be free from large or dead knots, shakes and blemishes. The chief defects found in a log of timber, besides those already mentioned, were—(*a*) cup-shakes, which were gaping openings, forming segments of circles between the annual rings; (*b*) starshakes, cracks that ran towards the center of the tree; and (*c*) heartshakes, that opened in the center of the tree and spread toward the bark. If a heartshake were straight across the butt, and ran up the log in a perfectly straight direction, it did no harm; but if it wound so as to get crosswise, by the time it got to the other end the log was spoilt for most purposes. This tendency of the trunks of trees to twist was very curious. Most trees were subject to it; the Spanish chestnut in our country, the worst in this respect, twisted so violently, that by the time the tree was sixty years old it was usually badly torn by shakes and began to decay at the heart. The lecturer did not think that this peculiarity in growth had been explained; but there were some very interesting facts in connection with the development of trees that seemed to bear on the question. However quietly a young tree might appear to grow, there was really a constant strain existing within it. The center of the stem was straining to elongate itself; the outer parts were holding it back. These forces, as a rule, balanced each other, so that they could only be discovered by experiment. It was easy to excite the fibers of a young plant in one place so that it would, of its own force, bend considerably out of the upright. Besides this, although a stem seemed to be growing regularly, there was a tendency to grow first on one side and then on another, so that a movement was set up such as was most strongly developed in the hop. When the stem of a large tree twisted without being affected by violent winds, it was evident that one of these forces connected with its growth had got the better of the other forces, so that the balance was not perfectly preserved. On the other hand, a young tree that had grown crooked, sometimes altered its habits so as to make new wood in a straight and regular manner. When that was so, we found in the center of that log the crooked wood of the young tree, and the history of its gradual amendment very clearly recorded. Mr. Blashill continued: we next come to the questions of felling and preparation for use. The best ages at which trees can be felled are, for oak, 100 to 200 years; Scotch pine and Norway spruce, 70 to 100; larch, ash and elm, 50 to 100; poplar, 30 to 50. The best time of the year for felling is the winter, because the tree is then most free from sap. Some trees may be felled soon after midsummer, because the sap is very quiet at that time. Oak is generally felled in the early spring—the worst time possible—because the bark, which is very valuable, is best obtained when the tree is full of sap. It is better to strip the bark off as the tree stands in the spring, and to fell it in the following autumn, when the sap has dried out of it. Teak is barked three years before being felled. It shrinks less than any wood in ordinary use, but it is said that this method renders the wood of teak more brittle. We have seen that the trunk of a growing tree is composed of wood in very different conditions. The interior is hard, comparatively dry, perhaps having its pores filled with resin or gum. The outer rings of wood are softer as they come nearer the bark, fuller of sap, more actively alive. Seasoning is the gradual drying of the whole log, so that the shrinkage of the outer part shall not be so rapid as to cause it to split and tear open before the interior has had time to part with its moisture. If timber is to be seasoned without artificial help, it should be stored over a dry surface free from vegetation, well packed off the ground, with free access of air, but not exposed to much wind. When squared it should be stored under cover to give shelter from rain, sun, and wind. So treated, oak will require as many months as the side of the log measures in inches. Fir will take half this time. The timber should then be cut into plank or large scantlings, and be still further exposed to the air, being so stacked that it cannot warp or twist. When it is cut to the sizes for which it is required to be used, it is again stacked until it becomes fully seasoned. Finally, it should be brought into a dry, warm room or shop till it is fit for joiner's work. After it has been wrought it must stand in the shop for a few weeks, until it has assumed the average condition of dryness that is permanently maintained by wood in our moist climate. It may then be finished off. If a round or square piece of wood has to be made thoroughly dry, it is best to bore a hole through the heart, so that the air may get access to the interior, and make it keep pace in drying with the outside, so that the shrinkage will be really equal all through. The length of time that has to be occupied by this natural process of drying, with the consequent expense, has induced many inventors to propose the drying of timber by artificial means. The most ancient method is that of drying in the smoke, which would be the smoke of wood fires. Besides drying it more rapidly than could be done by the gentle warmth of a room, the bitter deposit from the smoke was supposed to protect wood from insects. There is an old patent (Langton's) by which the sap is extracted from the green timber in a vacuum cylinder under heat. The length of time occupied and the cost prevent its use. Other systems for the application of considerable heat with the condensation of the extracted moisture are subject to the grave defect of causing irregular shrinkage with splitting of the wood, and though the cracks thus made close again to a great extent, the mischief done to wood that is intended for many important uses is incurable. For the use of the carpenter it is unfortunate that baulk timber and deals now seldom get any seasoning beyond the time requisite to convey them from the forest to the building, and the very imperfect seasoning the baulks get during their stay in the docks. Such timber, if closed up from the air near to moist walls or new pugging, will quickly develop dry rot, even in the upper floors of a house. Deals should have a year or two of open-air seasoning, being stacked with spaces between them, and should afterwards be gradually dried as they are required for use in the joiner's shop. Dry wainscot from Riga and Odessa are cut into thicknesses, and stacked for three, four, or five years, being placed on end, as the sap is supposed to run down more easily. Planks are stacked horizontally, with spaces between them. Such woods as mahogany, black walnut, ash, birch, and maple, are treated similarly for a shorter time. In all cases the ends of timber require protection from sun and wind, as they dry more rapidly than the other parts. One of the old methods of seasoning is to keep timber in water for a fortnight after being felled. A good deal of the sap is thus dried out of it, and it becomes more durable, but is not so strong. Steeping it for a longer time injures it, particularly if it is kept floating only partly covered with water. Boiling and steaming timber have long been tried, and the processes have been almost or quite abandoned. The effect will be to wash out the sap, as in steeping. A fresh plan of steaming has lately been introduced, and is said by some who have tried it to be efficient, as for many purposes it may very well be. There are many purposes for which the strength of wood is of less consequence dryness, or at least permanence of the same degree of dryness. The sap has been extracted by the air-pump, which must promote dryness; but this plan does not seem to have been much practised. The ordinary means of drying artificially are various methods of keeping up heat in a drying-room, generally by the use of waste steam from machinery. When wood has been cut up into small scantlings the drying can be hastened in this way; but the further the heat is raised beyond that of an ordinary room the greater is the risk of irregular drying and over-drying. There is a new process for seasoning boards by means of dry, cold air. The air is passed through a furnace, so as to make it dry; it is next cooled, and then made to circulate through the piles of wood, so that in a few hours the boards are dry. One or other of these processes will probably be found so far satisfactory as to be useful for a great variety of purposes. There are no purposes for which wood is used in which the question of seasoning is of more importance than the higher class of cabinet work and the making of musical instruments. The best makers of such articles are exceedingly shy of artificial seasoning. In organ-building, such woods as mahogany, black walnut, birch, red, yellow and white deal, and a large proportion of pine, are used. These are stacked under cover, being carefully packed so that the air has free access through each stack. Hard woods require from two to four years; soft woods from one to two years of this seasoning after being cut to sizes. Even the workshop must not be too warm. The best pianos are made of wood that has been stored, first (as regards the deals) in open stacks protected from sun and the penetration of rain, and finally in rooms, where all kinds of wood, cut to sizes, are subject to the very gentle warmth of 70°. The common sense of this question of seasoning is sufficiently obvious. Wood must not be dried so quickly that it will be made unsound by cracks. It must not be dried so much that it will absorb fresh moisture and swell when it comes into the atmosphere in which it has to permanently remain. It is not merely a question of time, but of judgment, the objects being to see that the timber is gradually reduced in scantling as it dries, and so treated in temperature and stacking that it neither splits nor gets out of shape. There is very great diversity in the details of different experiments on the loss of weight by seasoning. Oak appears to lose from something less than one-fifth to more than one-fourth of its weight. Other woods vary still more. Teak and pitch-pine lose very little. Woods that come from remote places get seasoned, in a great measure, before they reach this country. Paints or other appliances that would close up the pores must on no account be put on wood that is not sufficiently seasoned. When dry, they may be serviceable by preventing the absorption of moisture. If the wood is full of sap, decay will take place much quicker when painted than if it were left uncovered. One of the most important questions, as regards the soft wood especially, is the prevention of decay. When in use in a building, timber generally decays either by rotting, through becoming sodden with wet, or by what is called "dry rot," which is caused by slight moisture, warmth, and want of ventilation. For the prevention of decay, the kyanizing process, which consists of the application of corrosive sublimate by soaking, is effectual. The process of Sir William Burnett is still carried on by the firm established by him at Millwall. It does not seem that very much is required in order to make our resinous woods durable when exposed to the atmosphere. Complete exposure to the air, combined with the dryness of the ordinary atmosphere, is in itself a great preservative. Beech timber is useless in construction, as a building in which it is employed will be destroyed, chiefly through the attacks of insects, in a few years; but beech will last many years as a weather-boarding for such a building. In the Indies, such insects as the white ant destroy all woods that are not bitter, especially soft woods. When furniture is sent from England it may be partially protected by a coating of red lead; but if the insects get into the substance, they honeycomb it before anyone suspects that they are there. It is, therefore, advisable to impregnate the wood with some protective solution, by means of such machinery as has been mentioned. The essential oils, such as turpentine, have been recommended, but they are inflammable. Corrosive sublimate, arsenic, and other poisonous solutions of that class, seem most suitable. Creosoting is effectual, both as against decay and against insects, but it spoils timber for all of the best and finest purposes. The protection of wood from fire is a most important question, particularly as recent experience seems to show that we cannot depend on iron or stone. A heavy wooden beam will resist fire longer than any other beam or girder. The same with staircases. Such liquids as tungstate of soda could be forced into the substance of all wood used where fire is to be guarded against. Outward applications seem to be effectual in experiments tried on a small scale. To sum up the whole class of questions connected with seasoning, we want timber that will not shrink after it is brought into use, that will not warp or twist out of shape, will not decay through damp, and will not be destroyed by insects. Wood may also be indurated, that being the result of polishing and of varnishing to some extent. Upon the whole, it is desirable to encourage all means of treating wood, so that it may possess some of the advantages that are commonly attributed to iron and stone. In cutting up timber for use, the question of its grain as developed by the annual rings is of very great importance. The shrinkage being greater in the newer layers of wood, it must be cut so that this irregular shrinkage may be of no disadvantage in use. A plank taken out of the middle of a log will shrink at its sides more than in the middle; the boards that are cut out to right and left of this plank will curl outwards from the center of the log. If a log is cut into four quarters, the part of each quarter that is furthest from the center will shrink the most. Nothing requires such care in converting as oak timber, in which the medullary rays have so much influence. In order to show the beauty of the grain, as well as to provide wainscot boards that will be true in shape, it is necessary to get the boards as far as possible to radiate from the center to the outside of the log. If this is done, the medullary rays are cut through in many places, so as to show the silver grain. One method for doing this perfectly is shown in books, though I never heard of its being done in practice, the great expense and waste in sawing being an effectual obstacle. I have always had English oak "quartered," and then the boards have been sawn from alternate sides of each quarter—a method which insures at least eight perfect boards, and at least twice as many very good ones in regard to beauty of grain. Wainscot oak from Riga and Odessa comes to this country with two slabs taken off the opposite sides, and a cut clean through the center, or else it has the slabs taken off and a plank taken out of the middle. When it is partly seasoned, the plank has the center part taken out, as the part around the pith is likely to be unsound. Then each of the side logs is cut up into boards, several of which will go pretty nearly along the line of the medullary rays, and show the silver grain. Oak timber, as it was used in the beautiful Gothic timber roofs of the Middle Ages, and as it is still used in important parts of wooden ships, requires to be, not straight but bent. This bent timber is known as "compass" timber when it is 5 in. and upwards out of the straight in a length of 12 ft., and is more valued on that account. Ash timber does not appear to have any sapwood, all the wood being of the same color, and there are foreign timbers with the same peculiarity. It appears, however, that the worm finds out the part that is sapwood, so that it has the usual defect. In elm timber the sap is reckoned as good as the heart. The timber does not improve by seasoning, but should be used green, and even kept wet until wanted for use. When used in flooring, I have known the oldest elm boards shrink considerably if they were merely taken up and planed. We must not overlook the important uses of the finer kinds of wood when cut up as veneer. The fact that veneer is very much abused is no argument against its legitimate use. It should only be used in panels, so that the framing will be of solid wood of good, plain colors, to set off the beauty of the panels. The most beautiful veneers are still cut with the saw, about ten to sixteen to the inch, though knife-cut veneers are very largely used. By steaming large logs of timber and putting them in a lathe, the knife will pare off a continuous sheet from the thirtieth to the one-hundredth part of an inch. The chief woods used are rosewood, zebrawood, satinwood, tulipwood, mottled mahogany, walnut burrs, bird's-eye maple, birch, Hungarian ash, and sycamore, and there is a great variety of beautiful Colonial and American woods, producing every variety of color.

A RATIONAL POLICY OF PUBLIC WORKS.

By L. E. COOLEY, President Civil Engineers' Committee on National Public Works.

Journal of the Association of Engineering Societies.

[The theory of the argument is, that the utility of a system of public works must be apparent, in order to furnish a sound reason for providing a special service, or a change in the present service, for its conduct. In giving prominence to interior improvements, it is assumed that there is no difference of opinion as to the great importance of coast works.]

INTRODUCTION.

Is there need of better provision for a system of internal improvements?

If so, what action should be advised for determining a rational policy and providing a service for carrying it out?

To base the consideration of this question solely on the public weal, is to promote the highest justice to all interests.

If the utility of a system of internal improvements be admitted, the importance of a specially organized service is self-evident. If Congress is prepared to adopt a consistent and uniform policy toward public works, it is ready to provide an adequate service for their charge. That the time has come for the definite inauguration of such a policy may not be sufficiently clear to gain the general consent of our legislators. Meantime, local interests which can influence votes will dictate appropriations, and perhaps secure special commissions and appointees thereon. Congress, as hitherto with all irregular appropriations, will continue to assign their expenditure to some one of the great departments which may be provided with a bureau more or less well adapted for their disbursement.

To promote a change to a rational policy from the present wasteful and unfruitful system, if indeed it may be called a system, is the duty of a profession which can most clearly understand its deficiencies.

Any intermediate steps that might be taken would seem to afford greater possibilities for evil than the condition it is sought to remedy. To see any necessity for change is to recognize the whole truth; to urge its full conclusion is likely soonest to attain a desirable consummation, free from the suspicion of personal or class interests. Accepting these premises for the time being, the reasons for a policy different from that now prevailing are in order.

THE UTILITY OF A PUBLIC WORKS SYSTEM.

Competition by Water.—Lake craft from Chicago or Milwaukee to Buffalo or

Erie, receive from one-third to one-fourth the through rate by lake and rail to the sea-board*; or the lake rate per ton-mile is one-fourth to one-sixth the rail rate. If these rates may be assumed to represent relative cost of transportation, then it is simply a question of how far the size of boats may be reduced, how much their speed shall be lessened, or what difficulties of navigation are to be contended with, to bring the cost of water carriage up to that of rail. The margin is certainly ample to admit great possibilities in a well-considered waterway system.†

Commissioner Fink, of the Trunk Line pool, has stated that the Erie Canal influences rail rates to the seaboard as far west as St. Louis and south to the Ohio River. The Illinois and Michigan Canal, of less adequate proportions and with limited commerce, favors all the towns along its route with a rail rate much less than that of towns distant a day's journey by wagon.‡

The lines of boats on the upper Mississippi give great advantage in north and south rail rates to the cities along its course, and even the occasional boat which once or twice in a season may reach a Missouri river town, mitigates the railway tariff. The few months of intermittent navigation on the Ohio are profitably utilized by coal fleets, heavy products and even merchandise, and the lower Mississippi exercises an influence quite out of proportion to southward - bound commerce.§

* Statement by S. S. Merrill, manager of a line of lake boats, before the U. S. Senate Committee on Interstate Commerce, at the Chicago session, the past summer. The lake route is practically twice the rail distance by five different lines from Erie or Buffalo to the seaboard. Lake rates on coal from lower ports, less than one-third that to the Mississippi, for five times the distance.

† Previous to 1858, but 9½ feet could be carried through Lake St. Clair; 12 or 13 feet up to 1874, and 16 feet since. Present plans contemplate an ultimate depth of 20 feet for lake navigation. The great reduction in lake rates following increased draft and improvements in vessels and machinery, may be expected to continue beyond all hope of rail competition, when enormous capital accounts and fixed charges are considered.

‡ The railway commissioners' rate on wheat, generally adhered to at non-competitive points, is 7.2 cents per bushel for 130 miles. The rail rate from Henry to Chicago, 130 miles, is the same as canal rate, namely, 3 cents per bushel.

§ The influence of the Mississippi river on rates to Atlantic ports, especially from St. Louis, is discussed in the reports on Internal Commerce of the United States, by Joseph Nimmo, Jr., Chief of the Bureau of Statistics, Treasury Department. See Report for 1880, *et seq.* Also papers by Fink and other authorities.

Our waterways, undeveloped and unimproved and of inadequate capacity, in fragmentary systems and closed for a part of each year, frequently not in the direction of traffic requirements, afford their bordering towns cheaper rates and indirectly benefit the whole country.* It was repeatedly admitted by railway officials before the Interstate Commerce Committee of the U. S. Senate, the past summer, that the water route, though it may not carry a pound of freight, exercises a *moral* influence over rail rates. A channel that can be navigated is a latent force which becomes active when rates are pushed above a certain minimum.† If this be now true, what benefits may not be anticipated from the development of an adequate system, fully navigable at all times in the South, and, when not closed by ice, in the North?

France has, perhaps, a more fully developed waterway system than any other country, having expended $218,000,000 on 7,069 miles of interior or non-maritime lines.‡ Within the past few years she has been improving rivers of a class, at present, quite unworthy of attention here. Although rigidly controlling her railways, of which she becomes the owner after a limited time, she has recently given renewed attention to her waterways with a view to their fullest development in accordance with the latest studies; $270,000,000 have been set aside for the purpose by her Government and her municipalities, and this for a territory considerably less than the combined area of Illinois, Iowa, Wisconsin and Minnesota. Under the circumstance of full control and ultimate ownership of all highways of commerce, this may be taken as the unbiased judgment of her statesmen and engineers. How puny seems the river and harbor bill for a country like the United States!

Manchester, England, has recently concluded to bring the sea to her doors

* The far-reaching effect of competition is shown by Commissioner Vining of the Western Trunk Line Association. See *Railway Review*, Oct. 18, 1884: "Necessity for a Classification of Freight."

† "They can only increase their charges over the charges made by water routes to the extent that they offer additional advantages; while somewhat higher rates can be charged by the railroads, the basis of their charges are the charges made by water-lines."—Albert Fink, Sept. 17, 1873. before the U. S. Senate Committee on Labor and Education. Virtually the Chicago and St. Louis rates by water are the basis to which the rail rates of the country are adjusted.

‡ New lines authorized, 1,813 miles.

through a canal thirty-five miles long, to cost $40,000,000. The maximum rates are fixed at one-half the present rates by rail or canal from Liverpool.*

It would be a work of supererogation to cite further proof that water carriage in proper channels is the cheapest method of transportation. Was it not Lord Dundreary who noticed that all the great rivers ran by the big cities?

The Future System.—It requires but a superficial examination of our country to appreciate its possibilities in a magnificent public works system. Fringed about by a deeply indented coast, harbors in profusion invite fuller development. Great lakes and rivers, extending remotely from market points, drain basins unexampled in mineral and agricultural resources. Natural channels, susceptible of improvement to ample capacity, are well distributed. Topographical features favor the linking of the river systems to each other, to the lakes and to the seaboard.

The canal systems .of our fathers are of the past, and the day of meagre channels and small boats is drawing to a close. The railway is better adapted to the quick, detailed and distributive traffic of our country. Natural channel-ways, developed to a capacity suited to fleets and boats of large burden, so articulated at vantage points as to require no change of cargo—a great trunk system with tributary water-ways of indefinite extent, joining market points of heavy traffic origin and destination—this is the system of the future.†

It has been stated that the Mississippi Valley, comprising about one-third the territory of the United States, contains 15,000 miles of navigable streams; *i. e.*, streams which have been navigated and legally known as navigable. The question was investigated in 1881.* Taking the main river to Cairo and the basins of the Ohio, the upper Mississippi and the Missouri, 10,000 miles of rivers were found, the projects for which considered an improvement feasible, at reasonable cost, for boats of a large class. This estimate omitted the tributaries of the lower river and a great number of minor streams for which appropriations have been made. On the same basis the natural channels of the balance of our territory would readily raise the estimate to 20,000 miles. To make the system as complete as in France, by embracing minor streams and more extensive improvements, would give a mileage of not less than 50,000. To-day, 10,000 miles of improved channels would constitute a primary trunk system, about one-twelfth of the railway mileage, which would directly or indirectly regulate traffic charges throughout the country. Increasing density of population, traffic grown heavier and more concentrated, and the margin of profit on industry growing smaller, would gradually demand extensions of the system until developed to its limit of usefulness.

Waterways, as at present existing, in detached lengths, unsuited to economical transport, unavailable a good portion of each year, cannot be expected to attain great results, and yet their influence is admitted. Waterways should constitute connected systems as well as railways, and they should be so planned as to avoid transhipment as much as possible, the same capacity cannot everywhere be provided, but improvements can be based on a few well considered types, uniform throughout the country, in lieu of present methods by detached works without reference to other works with which they will some time constitute a system.

What can be afforded.—Our territory extends so widely as to make the traffic tax between the producer and the consumer, the agriculturalist and the manufacturer, the interior and the seaboard, a heavy burden. The amount by which this burden can be lightened is the measure of what can be afforded for internal improvements.

* Depth, 26 feet; lockage, 60½ feet; locks, 550 feet by 60 feet.

† Of what use are rivers? "To feed navigable canals," said James Brindley, the father of English canal engineering, more than a century ago. This remark, in a measure true at the time, became the chief dogma of canal engineers. The practice of this branch of the profession soon became fixed, and has shown little elasticity or advance under the changing requirements of the age, or the revolution wrought by the introduction of steam. Even as late as 1848, the Illinois & Michigan Canal, with meagre prism, was completed for horse boats alongside a river unusually well adapted to slack-water improvement for steamboats or a large class. The locks and dams on the lower Illinois is another case of reversion. Had dogma given way to wise forethought, the same expenditure could have resulted in a magnificent navigable channel from the Lakes to the Mississippi, and made of the Upper Illinois the Merrimac of the West.

* "Proceedings of the Missouri River Improvement Convention" (p. 59), St. Joseph, Mo., 1881; also, "A Plea for the Missouri River Improvement," by L. E. Cooley and S. H. Yonge, published by the City of Leavenworth, Kansas, 1884,

The National Government, from 1790 to 1879, expended on all our rivers and harbors, $81,747,604.45.*

The State of New York, up to 1873, had expended on her canal system an equal amount, or $81,577,993; and received therefrom in tolls, up to 1876, $128,067,030; while the surplus earnings on the Erie Canal alone, up to 1873, above cost, operating expenses and maintenance, were $40,175,594.† The indirect benefits to New York and to the whole country have been immeasurable.

At the end of 1884 the railways of the United States aggregated 125,150 miles, with a share capital and indebtedness of $7,676,399,054, or $61,400 per mile, and on this sum it endeavored to collect dividends. Although the year 1884 was one of unusual depression, the gross earnings amounted to $770,684,908, and the net earnings to $268,106,258, or $2,142.28 per mile. The average rate was 1.236 cents per ton-mile.

It is not proposed to argue any abstruse questions in political economy. It is evident that if a system of public works could have saved to the people 10 per cent. of the gross earnings in 1884, and this ratio of saving could be maintained by its construction, an expenditure of over $2,500,000,000 at 3 per cent. could be afforded for its development. If far better results are to be realized, then by that much would the general public benefit in a clear gain. The railways would still retain traffic ample for a reasonable return on their *fair cost*, for all lines judiciously located and properly constructed. In the greater prosperity that would ensue, an increase in that traffic for which the railway is best adapted would doubtless provide better returns. While it might not be expected that waterways would promote the construction of railways and enhance their value, such has been the result throughout the Mississippi Valley, and from the great lakes eastward.

It is impossible to infer to what degree of perfection $2,500,000,000 could bring a public works system. This much is certain, however, that Congress cannot expect to attain great results with the expenditures of 90 years, an amount less than the aid to the Pacific railways in their brief history.‡ A well-defined policy, a full studied scheme and annual appropriation reasonable in view of the purposes to be subserved, would gradually bring relief in reduced cost of transportation.

The value of navigable channels is gradually impressing itself on the people. Along lines of heavy traffic their cheapness is admitted. As a bulwark against extortionate rates even before demanded by traffic, they secure recognition. Every steamboat and ship owner is a free competitor for traffic, thus adjusting profits to those of general business. A traffic charge is a tax which it is the function of Government to lighten as much as may be possible.

If the claims for an interior system do not receive full assent, our coast and lake harbors of themselves can demand better provision. The increased draught of lake and ocean vessels makes deep entrances to harbors imperative. Every port on our 20,000 miles of coast line requires the watchful care and skill of the best service that can be provided. Many of these ports are at the outlets of great arterial systems which may carry the products of a nation to the seaboard, on its way to domestic or foreign markets; and they are likewise the natural entrepots through which the products of other lands may reach the great interior.

Can the growing sentiment of our people for interior and coast improvements, which is constantly breaking out in popular conventions and crude enactments in our legislative chambers, be indefinitely ignored?

THE GROWTH OF PRESENT METHODS.

A National Policy.—The policy of the General Government for the first half century of its existence was foreign to the construction and improvement of waterways and harbors, although the

* Four bills have been passed since, aggregating $53,813,235; and $4,250,000 has been paid on the South Pass jetty improvement. A partial list of the work done on rivers and harbors, and such canals as have been turned over to the general Government, by States, corporations and private individuals, up to 1879, aggregates an expenditure of $31,021,423.32. In aid of such work, the Government has granted 3,057-840 acres of the public domain.

† Cost, including that of the original canal, extraordinary repairs and improvements up to 1876, $49,160-986.93. The free canal system went into effect at the beginning of 1883.

‡ The subsidy to the Pacific railways was $64,623,-572. The principle and accrued interest, June 30, 1884, was $102,934,794.08. About 150,000,000 acres of land have been granted and about 50,000,000 patented or earned. It is reported that 100,000,000 may be forfeited at the will of Congress.

construction of national roads was largely entered upon. Notwithstanding the efforts of several of the States, notably New York in 1811, to induce Congress to undertake public works or to give aid, congressional action was limited to an occasional land grant for state enterprises, a practice that only grew to full fruition in the building of the land grant railways by private corporations. Accepting the policy of the General Government, the several States largely entered upon the construction of canal systems and even the improvement of rivers and harbors.

In this early day the constitutionality of public works construction by the United States, except as warranted by military necessity, was gravely argued, and is even now brought forward in relation to special schemes. The military necessity plea served some earlier projects and again came to the front at the close of the civil war.

Under the commerce clause of the constitution, the Supreme Court has defined as navigable waters of the United States, those that "form in their ordinary condition by themselves, or by uniting with other waters, a continued highway over which commerce is or may be carried on with other States or foreign countries in the customary modes in which such commerce is conducted by water." Although the earlier decisions run back fifty years, it is only since 1870* that the limits and powers of the General Government have been well defined, and even now there are many points undecided. The paramount jurisdiction of the General Government is assumed in recent river and harbor bills and bridge laws, and of late States have recognized their subordinate powers on domestic streams and in bridging navigable waters. The construction of artificial channels around obstructions has been for some years accepted as proper, and as links between natural systems they are obtaining similar recognition. In fact, it may be doubted if there is any limit to the powers of Congress to provide commercial highways in the interests of commerce.

The history of our waterways ascribes to them remarkable prosperity until the advent of the railway systems, and as pioneers in the first development of the country. During the speculative and constructive period, with the large profits and rapidly changing values incident to the inhabitation of new territory, the railway, even with heavy traffic charges, proved its adaptation, and the waterways gradually fell into disuse. With the development of market centers, furnishing a cargo or bulk traffic in place of the old coasting trade, with a settled and dense population and fixed industries, with lower margins of profits on which freight charges most seriously infringed, waterways have taken on new life, and their improvement is loudly called for. With the long-recognized importance of coast harbors, this call is co-extensive with our land.

The history of this question passes from a period when internal improvements were regarded as the peculiar function of the States, up through a marvelous development of transportation facilities by corporate capital, in which commerce has become a mighty problem of interstate concern, until a public works system is recognized as the province of the General Government. That the growth of this idea will in time find expression in proper legislation, no one can doubt. That it should, ere this, have resulted in a well-defined policy, is the belief of students of the subject.

Legislation.—Our public improvements have secured appropriations most largely through local and sectional influences. Great popular conventions are held to express to Congress the earnest desire of the people for improved waterways and harbors. In these conventions diverse interests often strive for expression, and even in Congress they not infrequently so antagonize each other as to defeat legislation of great public moment. The limits hitherto set for the river and harbor bill, the great number of projects demanding attention, and necessarily included, have resulted in the arbitrary scaling of estimates to a fraction of what is required in individual cases to prose-

* Sup. Ct. Decisions, 1870: "The Daniel Ball." The Grand River was declared to be a navigable stream and not a "domestic stream" solely under the jurisdiction of Michigan. The first important case was in regard to an exclusive franchise granted to R. R. Livingston and Robert Fulton for the navigation of the waters of the State of New York by boats moved by fire and steam. The doctrine was more fully defined in Gilman vs. Philadelphia and in the Wheeling bridge case, as also in the Rock Island bridge case.

cute work economically or to even achieve success.

That improvements should be local and diverse is to be expected. That there should be a medley of bridge laws, or none at all in some instances, is not strange. That even in connected or adjacent navigations, forming parts of a local system, there should be such diversity in permanent structures as to call for different classes of boats, is a legitimate result of present methods. That works should be undertaken which are totally separated from continuous navigable waters, or that expenditures should be made only remotely connected with the interests of navigation, need not be a matter of surprise. Do we wonder that the river and harbor bill should fall into disrepute, and the true friends of a public works policy pray that it may be killed annually until more rational methods can prevail?

The only effort which has been made to lay out a system of improvements was by the Windom Senate Committee of 1874. Although much interesting information was collected and some general recommendations of value made, no great result could be achieved by such a body, or by any body, in a brief space.

The study of internal improvements and their execution is the proper work of an organization constituted for that purpose. The local or sectional scheme should go directly to this department for examination, and reach our legislative halls only as a project in harmony with a general plan. Finally, in the elaboration of a general plan, we may suppose all local or sectional interests to have been properly consulted. By such methods, and appropriations commensurate with the purposes in view, will our public works assume a proper dignity.

Professional Organization.—With the growth of public improvements, the Military Engineer Corps is found in a neutral and powerless position. Originally, appropriations for works of military necessity, for roads or for explorations, were naturally delegated to the Secretary of War. That their disbursement should have been assigned to the Engineer Corps of the Army, even had other talent been then available, was proper, and the usage has continued to this time, although the purpose has largely changed.

Except by custom and implication, Army engineers have no legal or legislative status for civil work, and may be considered as virtually on detached duty. Without proper status, they are powerless to devise or recommend a system. Even an opinion, in accordance with military ethics, may be impertinent, and wise enactments must take the chance of discovery by men unfamiliar with the requirements. Without tenure in the work to which Army engineers are assigned, they are assigned, they certainly cannot provide a status for their civil employés.

Such conditions not generally understood, have naturally resulted in dissatisfaction, and it is not strange that under the spur of special interests, a remedy should have been discovered in the commission panacea. The apparent advantage to one section through a commission leads to a struggle for like advantage elsewhere, until every large sectional interest may be expected to insist on its commission. This leads to a gradual disintegration of responsibility. Appointments become a matter of influence, with no assurance of training or skill for the work, and the tendency is inevitable to self-seeking and political control.

Although commissions, *per se*, may have been a benefit to our public works in mooted questions and special installations, yet, thereby, an organization has not been provided for their better conduct, nor has a desirable tendency been inaugurated. It has gone too far, however, to warrant no action or a return to the old regimen, and it should be wisely met by comprehensive legislation.

It is certain that any organization thus far constituted is quite unsuited to the requirements. Until, however, Congress defines a policy toward public works, a special organization can have little reason for existing.

THE DEFICIENCIES OF THE PRESENT ORGANIZATION.

To present without bias the deficiencies of the present river and harbor service is no light or enviable task. The organization of the Engineer Bureau is purely military, and solely as an arm of the military establishment is its policy defined. It has no proper legislative sanction for civil work, this being in the nature of a detached service by assignment of the

Secretary of War, originally to works of military necessity. Adequate training and experience are not demanded for important civil duties, and officers are transferred from time to time with too little regard for the interests in which they are enjoyed. It cannot well be otherwise where all duty must be subordinated to the military requirement. All laws, regulations and rulings are essentially military. How ill adapted they may be to the requirements of civil work, is chiefly known to those who have had experience under them. Regulations in regard to purchases, contracts, property; in regard to vouchers and reports of all kinds, are elaborately annoying, greatly increasing the cost of supervision, often tying the hands of the resident engineer, or even defeating success in work requiring dispatch. A set of regulations based on the field requirements of civil work would promote sound business methods, but this is clearly impracticable until the whole matter is formally delegated.

The Corps of Engineers, U. S. A., at present comprises 112 members; of these, 35 are engaged in strictly military duty, 51 in strictly civil duty, while the balance have both military and civil duties. If the assignments be followed up in detail, it is found that, with few exceptions, officers attain the rank of captain before assignment to civil work; in other words, that five or six years of post-graduate study and experience is regarded as essential to the completion of their military training.

For their civil work, no special course of study, preparation, experience or aptitude is made a pre-requisite; yet no capable engineer officer will say that his problems of civil engineering taxed him less, or were less difficult than those of his military experience.

The first civil assignment is usually as assistant to an officer of experience. As preparation for actual charge has not been made, the duties performed are generally nominal. Thanks, however, to an excellent training, experience in time may remedy deficiencies, though the lack of detail knowledge of field practice and construction may be sufficiently apparent.

Each district officer is directly responsible to the Chief of Engineers only, who, with divided duties, is supposed to consider and approve every project in the United States. The relief afforded by an occasional board is not a comprehensive one, and, practically, there is no inspection service. The corps boasts of many civil engineers of high attainment, and that any success should be reached under a lack of proper method, is gratifying evidence of what might result from a definitive policy.

"Military and civil methods of administration are entirely diverse, and proceed upon diametrically opposed theories. The military officer plans and commands; the civil officer hears, weighs and decides."* That ideas are sometimes outranked in boards of military engineers, is the evidence of junior members. In like manner, may the subordinate service fail of a true development.

It has been remarked that the man of engineering habits of thought is a poor field officer.† If so, how far is a military training adapted to making the best civil engineer? One thing is certain, that the student who has mastered his course in a good engineering school and had five or six years' experience as assistant under a competent chief and in commercial methods, has fuller qualifications than the officer, who comes to his work after his post-graduate military service, a novice except in ability to organize. This of itself is a full argument for more rational methods.

Perhaps the most serious defect of our Corps of Engineers as an organization for civil work lies in the fact that responsible position is attained by transfer from a service of little similarity, and without antecedent training and experience; while the great body of whom technical knowledge and skill are required, perhaps equally competent, certainly with special training and years of experience, are ineligible. This class of men, under the general title of civil assistants, outnumbers the officers from three to six times. Their employment is of course temporary, depending on the annual appropriation bill. However competent or ambitious to make this specialty a life work, they

* Major J. W. Powell, Director of the U. S. Geological Survey, before a joint committee of the two houses of Congress.

† Another phase is illustrated in a recent remark of Adj -General Drum, in regard to the value of an experience in civil life, as evidenced by the great leaders which the late war brought to the front. He might also have cited the records of army and navy officers who have served in the Coast Survey.

are confronted by uncertain tenure of position and ineligibility for responsible charge. In fact, have we not the anomaly of a service, in which, as a general thing, the superior or responsible officers are unfamiliar with the field duties which they are called upon to direct and supervise? Does not this reverse the logic and the method of all human experience?

This condition cannot result in the best service. The time of the civil assistant on Government work does not average three years, or in other words, when some competence in a difficult specialty is attained at Government expense, it is immediately thrown away. The best talent of course, will not remain without hope of future reward, and ever in the face of the growing conviction that the special experience acquired can avail little in other pursuits. It is not strange, therefore, that a large proportion of our best technical graduates should enter a service to find out their mistake, and resign with more or less resentment toward a condition of affairs in which all concerned are alike powerless to remedy.

The deficiencies of the service grow out of legislative inadvertence and military point of view. It is no plea of justice to the civilian, that could, of itself, demand a change. There is but one question, and that is—what is most expedient, or what will secure the best result? All that can be insisted upon is, that the present plan, or rather no plan, for it has grown like Topsy, is most ill adapted, and that a well considered change is demanded in the interest of a better service. All familiar with the matter recognize this, and it remains to define its character.

SUGGESTIONS FOR A SPECIAL ORGANIZATION.

The wise man is ready to rebuild when he tears down. Unless a well digested system can be substituted, to argue a change is folly. The interests concerned are far too important for other than grave deliberation and conservative methods. If we have not faith that Congress, recognizing the advisability of change, will order wisely, then far better to have left our efforts undone, unless, indeed, they should ameliorate somewhat the inevitable.

A cursory study of our river systems, lakes and coasts, suggests the outline of an organization adapted to the requirements. The country naturally segregates into several grand divisions or departments within each of which there is such similarity in physical features, such community of interests, as to demand related works or plans in mutual harmony. These grand divisions subdivide into districts of less individuality, but integral members of the group which constitute the department. Adjacent departments will have much to consider in common, much to harmonize in the general development of trunk lines and the fixing of standard requirements for improvements of similar capacity.

Let the district be taken as the unit, with an officer in charge, and an organization competent for the multifarious duties involved in the design and execution of work. The several district officers may constitute a board, charged with the common interests and general plans for the department. Its chief should have no special charge, but should act as executive officer of the board. The several department chiefs may constitute a central board for the consideration of wider interests and the supervision and development of the public works system as a whole.

Within the district, resident engineers and assistants must be provided, down to the lowest grade requiring technical training, skill and ability. Starting with this grade, which may be one of probation, promotion should be step by step in accordance with a well-advised plan, preserving, however, elasticity enough to utilize the best thought in the profession. Such a system would not be unlike that of Prussia, in which all officials are educated and trained for their work as civil engineers.

Having decided upon a policy and the character of an organization, it is evident that to create it *de novo* and develop it to full efficiency, is a work of years. It is a truth that many engineers too little appreciate that river and harbor work is pre-eminently a specialty, requiring a high order of analytical ability, executive capacity and skill, to cope with active forces of destruction. The judgment acquired by special experience is not to be lightly thrown away.

As before stated, less than one-half the Engineer Corps is at present required for military duty, although the prospective and necessary work on our sea-coast defenses may soon demand quite its entire services. So there is now available over one-half the Engineer Corps as the nucleus of a civil establishment; and, with such civil assistants as may have developed special fitness, a fair working organization could be provided at once. It would be a matter of three or four years only before the new organization had become a consolidated, well-adjusted, living force, utilizing all the available experience and gradually establishing itself on a civil basis.

The organizing ability possessed by many of our engineer officers would be of the greatest service in the earlier stages of the new establishment. With the law intelligently framed and its provisions carefully worked out, the execucution could not be left to more willing or appreciative hands; and doubtless many of attainment in civil work would elect permanent appointments in the new service. The deficiencies of our present no-system are too well recognized by those concerned, not to make a wise remedy devoutly to be wished. Thinking men will not resist a change which insures better results, provided their vested interests are in some manner conserved.

WHAT SHOULD BE RECOMMENDED?

If the various phases of this subject have been clearly presented, then it is apparent that there has been a gradual change in attitude on the part of the United States toward internal improvements; that the time is approaching, if not already here, when the formal adoption of a well-considered policy will be necessary; that hitherto appropriations have been irregularly made, largely through the influence of local or sectional interests and without a general purpose; that their expenditure has been delegated, like all irregular appropriations, to one of the departments for disbursement; that this disbursement has been assigned to a military bureau, not organized for civil work, and having no legislative status therefor; that this has not, and cannot, for reasons not generally understood, be satisfactory; that various interests have inaugurated the idea of commissions which, however well adapted to particular purposes, tend to an undesirable end; and that action should be taken looking to a rational policy and the provision of a special organization for its execution.

The general character of an organization which would seem to be adapted to the requirements of our great territory has been outlined, and ideas advanced as to the best method of attaining its consummation. It has been shown how all projects may be presented in accordance with a well advised plan, thus doing away with the unseemly strife of section, locality and district, and how great results may be attained for the common weal through a system of public improvements. While it is our privilege and duty as citizens to discuss these matters, having reached our conclusions, it is incumbent upon us as professional men to point out the road to a solution.

It is evident that the consideration of this subject involves many complex questions. The work which is to be performed must be well understood. An organization which will secure the highest professional results and be in harmony with the genius of our institutions must be provided, and the legislation adapted to its needs well outlined. When the main requirements have been studied, experience abroad, so far as it may have a bearing, should be considered, and conclusions so matured as to eliminate purely individual opinion.

It is believed that the whole matter is in such shape as to make it impracticable to attain a definite system by a gradual change, or a species of growth. It will require time to bring those concerned to a full realization of the state of affairs and to an agreement as to a wise course to follow. To fly from the evils we have to those we know not of, can be ill afforded.

Therefore, it would seem wise of Congress to provide a board of Army and Civil Engineers, acquainted with this matter and realizing the necessity for a change, to consider the whole question of legislation and organization. Such a board could collate all the thought pertinent to the subject, and present its conclusions with recommendations for the consideration of Congress.

As engineers, we would feel confident that the subject would be handled as wisely as could be provided for, and that, for a purely professional organization, Congress would give heed to the conclusions.

SUGGESTIONS FOR A "DEPARTMENT OF PUBLIC WORKS."

The executive departments of the government present a curious medley of bureaus designed for sundry and various useful and special purposes. Of the seven great departments, three, those of State, Justice and the Post-office, confine themselves strictly to their special work. The Navy Department indulges in occasional canal surveying. The War Department takes upon itself Meteorology, Geographical and Geodetic surveys and Internal Improvements. The Treasury has a Light-house establishment, a Coast and Geodetic survey, a Public Buildings bureau, a Marine Hospital service, a Bureau of Statistics, a Steamboat Inspection service, a Life Saving service, a Revenue Marine, etc. The Interior has a Fish Commission, Geological surveys, Patents, Land surveys, Pensions, Indian Affairs, Census, Pacific Railway Commission, Capitol Building, etc.

It is apparent that the majority of these assignments are utterly incongruous. They have frequently come about through the recommendation of cabinet officers, under the initiative of some ambitious and stirring subordinate. Some of these bureaus are misplaced or in the wrong department and could be transferred with good results, while other departments should be confined strictly to the work for which they were organized. Why the Treasury should concern itself with other matters than those of finance, or the Navy and War Departments indulge in work foreign to their purpose, is anomalous. The special bureaus cannot assimilate the general service of the departments. It is not easy to provide the special organization, rules and supervision, which may be required.* These bureaus become, in nature, petty, semi-independent satrapies.

That it would be wise to segregate all our technical bureaus, or those requiring scientific and constructive skill, from their present unrelated departments, and aggregate them in a department by themselves, cannot be seriously questioned. Harmony in organization, regulations well adapted to the work, proper supervision, and the interchange of special experience, would all be promoted. Such a department would have its various purely scientific bureaus, its bureau of surveys, of architecture, of internal improvements, etc., all based on such a thorough civil service as must result where technical attainment is uniformly required.

Some of the bureaus referred to have been the subject of agitation with a view to better or more rational methods. Sooner or later all these interests must center about the common idea of a department.

The adoption of a consistent policy towards our public works and the provision of an organization especially adapted to their requirements, is a purpose in which the engineers of our country can unite for the highest public good.

At the same time, the status of our profession may be promoted in greater degree than by the solution of any other problem of our time to which we may lend our consideration and effort.

* The more onerous duty of properly supervising a technical bureau is noted in a recent report of a committee of the National Academy of Sciences. Irregular methods of business are encouraged by general regulations which cannot be adapted to the special requirements.

In the fiscal year ended June 30th, 1882, the number of engines shipped did not exceed 133, the estimated value being $1,455,717. Of the 282 locomotives exported from the United States in 1883–4, 65 went to the Argentine Republic, 49 to the United States of Colombia and Panama, 34 to Mexico, 32 to Brazil, 27 to the Dominion of Canada, 19 to Chili, 14 to Australia, 13 to Central America, 14 to Cuba, 6 to Spain, 3 to San Domingo, 3 to Sweden, 2 to Venezuela, and 1 to England. The number shipped in the fiscal year ending June 30th, 1881, was 99; in the year 1882, 133; in the year 1883, 219; and in the year ending June 30th, 1884, 282. During the ten years ending with June 30th 1884, the Americans sent 434 locomotives to various parts of South America, 203 going to Brazil, 84 to Colombia, 72 to the Argentine Republic, 37 to Peru, and 31 to Chili. During the same period of ten years, Canada and British Columbia imported 208 American locomotives, valued at £381,626; Mexico, 167, valued at £361,740; Australia 113, valued at £215,834; Cuba 88, valued at $772,911; Russia 58, valued at $778,500 Central America 22, valued at £21,644, and Turkey 12, valued at £36,400. It seems very remarkable that countries oppressed with heavy protective duties should be able to compete so successfully with free-trade England. Political economists would do well to supply an explanation.

TOPOGRAPHIC SURVEYS OF STATES.

By H. F. WALLING,

Member of Boston Society Civil Engineers.

The initiation of co-operative State surveys in this country having inaugurated a new departure in topography, a complete history of previous efforts in this work throughout the country would have a special interest at this time. Not having the requisite data, however, I can only speak of them in a brief and imperfect way.

Up to about 1850, such maps of the older States as had been published were nearly all made at the cost of the respective State Governments, or were liberally patronized by them. This was the case in New York, Pennsylvania, Maryland, Virginia, Georgia, Alabama and Mississippi. The maps of these States were in general compilations from the plans of original land surveys. In 1844, Massachusetts caused to be published an exceptionally good map of the State, from special surveys made at the cost of the State and of the several towns. The geodetic basis of this map was the triangulation of Mr. Simeon Borden, and, as you are aware, it was a very well executed work. The details of topography, however, were worked out by the local town surveyors, whose methods, as might be supposed, were incongruous and generally defective, producing results which fell very far short of the precision which accompanied Mr. Borden's work. In spite of this imperfection, however, the map as then published far excelled any other State map in general accuracy and completeness of detail, nor does it suffer, considering the difference of scale, in comparison with the original Ordnance map of England. From the year 1850 up to the commencement of the civil war in 1861, and for some ten or twelve years after the close of the war, the demand for maps giving more local details than had been shown upon previous maps became sufficient to induce surveyors to engage in their publication, a portion of the expense being in some cases defrayed by State, county or municipal appropriations. Maps of towns and counties, afterward compiled into State maps, were made in this way, almost entirely from original surveys, in all of the New England States, New York, Pennsylvania, Ohio and Maryland. Large maps of some of the States west of Ohio were also published from time to time. Since the construction of these Western maps consisted principally in compilation from the United States Land Survey plans, the labor in preparing them was much less than in the Eastern States.

Commercial Maps.—Maps made with no means of defraying the cost other than from proceeds of sales have been styled "commercial maps," in distinction from maps produced at the cost of Government, the surveys for which are sometimes called "scientific surveys;" but I think the propriety of the designation is, in some cases, questionable. A survey may present the general features of the country with a considerable degree of accuracy, but if the details are erroneously represented in important respects, it is manifestly an incongruity to denominate such work a scientific survey. A comparison of some of the Government surveys of Western territorial regions, where two independent surveys overlap each other, proves by their discrepancies the inaccuracy of one or both the surveys. On the other hand, comparisons of some of the commercial maps with subsequently published Government maps, shows close correspondence, and as there is no reason to suppose that the latter are copied from the former, it follows that even a commercial map may be worthy of credit so far as it goes.

It should be observed that until quite recently *all* of the maps heretofore published in this country, whether by the Government or by individuals, with a very few exceptions, are destitute of accurate hypsometric information. The more notable exceptions are the topographic work of the United States Coast and Geodetic Survey, of the United States Geological Survey, principally in the Western territories, of some mining engineers who have made admirable maps showing portions of the anthracite coal fields of Pennsylvania, and of the Second Geological Survey of Pennsylvania in special maps of limited areas in that State.

The wholesale condemnation which certain scientific critics have from time to time bestowed upon commercial maps, as such, not discriminating between those which have been carefully made from original work and other mere compilations from Government explorations, etc., which perpetuate from year to year, the original errors of their sources of information, indicates an unjustifiable lack of knowledge on the part of the critic, of the amount of original and really valuable information which some of these commercial maps embody. They have rendered valuable service to railroad and hydraulic engineers, to county and town officers, and even to geologists and other naturalists and scientific investigators. Besides these, many intelligent citizens, realizing the value of the maps for their own more private uses, have, by bestowing their patronage upon the surveyors, enabled them to publish these maps. If competent experts found on examination that these maps were erroneous and unworthy of credit, it would be their duty, in behalf of the public, to expose their unworthiness by pointing out the inaccuracies, etc. But it is hardly justifiable to condemn them *en masse* merely on account of their self-sustaining origin, or because the mechanical execution was not upon so expensive a scale as might have been possible under more favorable conditions. My apology for bringing this somewhat unprofessional subject before the Society is a feeling that injustice has been done to a number of local map makers in the New England and Middle States, who at their own cost and risk, during the last thirty-five years, have materially added to the previous knowledge of local topography, so far, at least, as it pertains to horizontal relations.

County Maps of Massachusetts.—I now beg your further indulgence for a brief account of some of the methods employed in my own work in Massachusetts some thirty years ago. This is done principally for the purpose of showing what can be accomplished at a comparatively small cost. It is not cited as an example to be followed, but rather as one whose faults and shortcomings are to be avoided when the means of carrying on the work in a better manner are available.

Having previously made surveys and maps of a number of towns and cities in the State, which were generally paid for by municipal appropriations, I undertook in 1854 the construction of a separate map of each county in the State, excepting the small counties of Suffolk, Dukes and Nantucket, which were included on sheets containing larger adjacent counties. The materials then in existence for such as set of maps included, first, the excellent triangulation made by Mr. Borden some fifteen years before, which had been used as the basis of the official map above mentioned; second, the town surveys ordered by the Legislature and made in 1830 and 1831, from which Mr. Borden compiled the details of his map; and third, more recent town and city maps, including those made by myself, already mentioned. The latter material was to be used, so far as it went, but it constituted a very small portion of what was required. The old town maps, although drawn to a scale two or three times as large as was proposed for the new county maps, were, in many respects, too inaccurate for use. A new survey was accordingly undertaken of all the public highways in the State. A careful estimate of the possibilities of remuneration limited the cost of the survey, including field and office work, to about one dollar and a half per square mile; and, ultimately, this was about the average cost. Hypsometry, as a feature of topographic maps, was at that time only undertaken in a few European Government surveys, made at great expense; and while I fully recognized its value, it was, of course, excluded unless the cost could be defrayed at public expense.*

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* Before undertaking the work as a private enterprise, I had attempted to procnre State legislative action in its behalf, and the subject was referred by the General Court to their Committee on Edncation. Professor Arnold Gnyot, then a resident of Cambridge, and Mr. Simeon Borden kindly interested themselves in the project which I presented, and nrged upon the committee the acceptance of my proposal to make a hypsometric snrvey by tachiometric methods—that is, by the use of graphic triangnlation stadia, vertical angles, etc., in connection with traverses of the roads, at a cost of $25,000. These tachiometric methods had then recently been introdnced in Europe by M. Porro, a noted Italian topographer. The committee reported a resolve authorizing the snrvey as proposed (see Honse Doc. 170, Mass. Leg.,

The scope of the work I had undertaken included the representation of roads, railroads, streams, ponds, marshes, the sea coast, with its capes, bays, inlets, and islands, and of important buildings, including dwellings, churches, schoolhouses, mills, manufactories, stores, etc. Some hachure sketches of prominent hills, in accordance with the imperfect fashion of the time, indicated the existence of slopes, more or less steep, and served to show where high ground or rough country was to be found, but gave no definite information in regard to actual heights or the true forms of relief. Fortunately, the entire coast line of the State was shown on the published or manuscript maps of the United States Coast Survey, together with a narrow strip of the adjacent land. So far as it went, this data was all that could be desired. The town maps furnished to the State archives, according to law, in 1831, in advance of Mr. Borden's triangulation, gave representations of town boundaries, roads, streams and ponds. These representations were fairly correct in the groupings of the various features in regard to the relative positions of objects when referred to those immediately adjacent, but owing to the imperfect methods of surveying and want of skill in platting or graphic representation, the map of a town, as a whole, was frequently more or less distorted and deformed. This was readily detected by the discordance between maps of adjacent towns along common boundaries and the impossibility of fitting a number of maps together into a larger continuous map. Since these maps, however, were made by local surveyors, whose knowledge of the general relative positions of roads, streams, water surfaces, etc., would be likely, from the nature of their occupation, to be as thorough as that of any class of people, and, in the main, correct, I made use of them to some extent for drainage representation, etc., under a careful system of checks, to be hereafter described.

Having for the basis of the proposed county maps the Coast Survey and Mr. Borden's triangulations, the plan was adopted of traversing all the public highways by course and distance, using the ordinary surveyor's compass for directions, and the revolutions of a wheel for distances. I wish to say a few words here in regard to the comparative usefulness of a wheel for measuring distances along roads. Though less accurate than a chain in the hands of skillful chainmen, it has the merit of economy, since one person with a compass and odometer can do the work of a party of three with a compass and chain. Then, the inaccuracies due to the inequality of the surface are much less on common roads than, in the absence of tests, would be supposed. In fact, on the ordinary roads of Massachusetts, which usually change their directions in short distances, the error from this cause becomes inappreciable in platting to a scale not larger than $\frac{1}{20000}$, except in long, straight stretches of hilly road, Moreover, there is little or no liability to an accumulation of errors of counting or reading, as with the chain or stadia. For example, if an error were made in reading the dial of the odometer, which usually registers from zero to 1,000 revolutions of the wheel, the error would not accumulate, but would be taken from one adjacent course and added to the other, so that if the change in direction was not great, the resulting error would be slight. In fact, where readings are frequently made in noting features of local topography, buildings, stream crossings, etc., an error of reading is often detected by its incongruity with adjacent readings. In stadia measurements, the distances must be reduced to horizontality, and in ascending or descending, unless the rod is held perpendicular to the slope, another correction becomes necessary, if absolute precision is required. But for traversing across fields, meandering streams, etc., the wheel is unavailable, and, for topographic work, stadia measurements seem preferable to any known method for rapidity and convenience. By the system of traverses adopted, all the highways were surveyed and platted continuously in a network. Each closed circuit of this network not only checked itself, but served to check adjacent circuits. Usually the errors of closure did not exceed one or

1854), and it had many friends in the Legislature; but the party in power had not the courage to risk being charged with extravagance by their opponents, and the subject was, by a small majority, referred to the next Legislature, where another resolve was reported favoring the work, which was again referred, however, to the succeeding Legislature (see House Doc. 294, Mass. Leg., 1855).

two per cent. of the distance traversed. An abnormally large gap in the closure of a circuit was checked by the closures of adjacent circuits until its approximate locality was established between two adjacent road junctions, where, by carefully studying the notes, comparing the sketched with the platted angles, the error was, in most cases, detected, being found due to some obviously erroneous reading of the compass or odometer; and finally the few undetected errors, when sufficiently important, were corrected by a resurvey of the defective portion. Upon the final adjustment of the network of roads, the other details of topography, namely, the dwellings, streams, etc., were supplemented. The field notes were first platted upon a scale of $\frac{1}{20000}$, that of the published maps varying from $\frac{1}{40000}$ to $\frac{1}{63360}$.

In order to reduce the work to a geodetic basis, and, as far as possible, to eliminate errors arising from inaccuracy of standard, etc., the traverses were connected with all the primary and secondary stations of the trigonometric surveys, which could be identified upon the ground, and these stations were marked upon the platted network of roads. Parallels and meridians were then interpolated between the stations for each minute of latitude and longitude, giving the residual seconds their proper value, and dividing the remaining spaces into the proper number of equal parts. A true projection in minutes being made on the publication scale, the original draft was reduced into its proper place, square minute by square minute. The ratio of reduction from the original draft to the publication scale agreed very closely, showing the general accuracy of the standard and of the graphic work, the difference being hardly greater than might have been caused by hygrometric changes in the paper.

This brief outline of methods and checks used in the construction of county maps in Massachusetts, now more than twenty-five years old, will give some means of judging whether or not they possessed a value commensurate with their cost in the more exact delineation than had previously been made of horizontal relations between the objects represented. It is quite evident, however, that whatever may have been the character or usefulness of the maps then made, the time has arrived when better methods and more precise results are required. While it is by no means necessary or advisable to entirely discard the method of traversing by which all the minute sinuosities of roads, streams, etc., are rapidly and economically ascertained, this method should be made subsidiary to the more exact processes of triangulation, which should be carried much further into detail than before.

Triangulation.

It is quite unnecessary to discuss before this Society the superiority of triangulation over traverse measurements as a means of determining positions. Starting from a base line measured with the refinements now attainable, the large theodolites constructed for the great geodetic surveys of the world are capable of measuring angles to within a quarter of a second, a degree of precision which renders it possible, as is claimed for the geodetic survey of British India, to determine the ratios between the sides of a network of geodetic triangles to within a theoretic error limit of one two-millionth part of the distance determined. (Address of General J. T. Walker to the Geographical Section of the British Association for the Advancement of Science. See Van Nostrand's Engineering Magazine, January, 1886, p. 71.) In the geodetic work of the United States Coast Survey for the Eastern Atlantic States, the error limit does not exceed $\frac{1}{288000}$, or less than a foot in fifty miles. (U. S. Coast Survey Report for 1865, p. 195.) For secondary triangulation—that is, the cutting up of the larger geodetic triangles into smaller ones for use in topographic work, etc.—instruments reading to 10″ or even 20″ are considered sufficiently powerful, and with them a precision which would limit the error to one foot in five or ten miles should be easily attainable. Such instruments are not difficult to transport, and there seems to be no advantage in the use of smaller instruments for the preliminary triangulation of a topographic survey.

Graphic Triangulation.—Triangulation, however, in a well-conducted survey by no means ceases with the instrumental and computed work. It is carried on by graphic processes upon a plane table until it reaches a stage where the triangles are sufficiently small to allow the interpolation of details by stadia measurements, pacing or even eye estimates and sketches. Stadia measurements must be regarded, moreover, as really belonging to the series of triangulation determinations in which the triangles are quite "ill-conditioned," that is, the known base, read off from the rod, is very small compared with the required side, or the distance between the reading instrument and the rod. The solution of these triangles by simple inspection sustains a relation to computation work similar to that of the slide rule. Such measurements can only be used to advantage for comparatively short distances, one thousand feet being about the maximum distance from the instrument at which distances can be read with sufficient precision.

Eye Estimates.—Eye estimates, even, are a species of triangulation. They are probably made by an unconscious comparison of sensations which accompany an adjustment of the focal length of the crystalline lens supplemented by a stereoscopic adjustment of the optical axes of the two eyes.

They are aided, where circumstances will permit, by comparisons of spaces occupied upon the retina by the images of fences, buildings, trees, animals and other objects of known size at different distances. Another aid to eye estimates is found in "aerial perspective," as it is termed by artists, or a certain haziness caused by minute opaque particles in the air, tinging objects with a purplish color, gradually changing to a blue approaching that of the sky as the distance increases. This change of color and the gradual loss of distinctness and merging of objects into each other afford a rough measure of relative distance.*

The bases of the triangles in the cases of eye adjustment are, first, the diameter of the crystalline lens at its opening, and, second, where the stereoscopic adjustment is made, the space between the two eyes. It must be remembered that there is no cotemporaneous scale of comparison for eye estimates. They are only obtained by a comparison of present sensations with former experiences, in which distances were estimated and verified by reliable measurements. It may be questioned, even, whether eye adjustments can practically be made in absolute conformity to the distance, and whether attempted adjustments are not affected by the personal condition of rest, fatigue, excitement, etc. It must be admitted, however, that in this, as in other uses of the senses, continual practice will be likely to lead to a remarkable degree of skill. Some of the topographers of the Geological Survey, for example, have attained an eminent degree of proficiency in eye estimation, and are able to sketch upon their field sheets the topography within a radius of several miles around each station occupied, and sketches so made are said to fit each other fairly well where they join or overlap. Where the limit of time and cost renders it necessary for each topographer to cover some thousands of square miles in a season with a sketch map of previously unexplored country, which shall give a general view of its salient features until a more careful survey is available, the use of "sketching stations" and eye estimates over such extended areas may be unavoidable, but it is quite evident that for State surveys such estimates must be limited to short distances and for the location of comparatively unimportant objects.

When at length the triangulation processes, including estimates of distances, cease, the topographer completes his work by sketching in from point to point the irregular curves which express the contours of the surface. Here his success depends upon a sense of form and proportion comparable with that of the landscape or portrait painter.

Amount of Preliminary Instrumental Triangulation Needed.—We are now confronted with the question, how much instrumental and computed triangulation should precede the final graphic or plane table work in the survey of a comparatively well-settled State, like the New England States, New York, New Jersey, Pennsylvania, etc.? This will depend in part upon the scale of the map to be constructed, since the scale will govern the

* In the discussion which followed the reading of the paper, Mr. Fred. Brooks remarked that the distances of objects seen across water were deceptive, owing to the absence of objects of comparison, and that an unusual clearness of the air in mountain regions caused distant objects to appear nearer than they really were.

area to be included in the field sheets, which may conveniently be used. It is considered indispensable that each plane table sheet shall contain at least three precisely determined points, laid down upon it in advance of its use in the field, two of them serving for a base, and the third for verification. These three points should be spread apart in an advantageous manner, be intervisible and command views of other controlling points coming within the limits of the sheet and suitable for occupation. While in skillful hands and with a good plane table, the accuracy with which triangulation may be performed is commensurate with the scale of the work, it is also true that many advantages would accrue from having numerous well chosen points located upon the sheet with the precision of numerical computation, since it is evident that the topographer could then proceed with certainty and dispatch to fill in the spaces between the smaller triangles thus formed; but the cost of graphic triangulation being somewhat less than that of the computed work, the question where the latter shall cease and the graphic work commence becomes one of relative value and cost. The cost of the field work for determining stations more than two or three miles apart is not greatly different in the two methods, but the additional cost of computation swells the expense of the instrumental method. Some of the principal officers of the United States Coast and Geodetic Survey hold to the opinion that at least one computed position should be given in every square mile of area for the best results in plane table work. Other skillful topographers are satisfied with stations three or four miles distant from each other. If, as in Massachusetts, the monuments marking angles in state, county and town boundaries are to be determined by computed triangulation, these determinations, with the auxiliary stations needed to reach them, will furnish points averaging less than three miles between adjacent stations and will constitute a sufficient amount of secondary triangulation to precede plane table work and enable the topographer to carry it on with rapidity and precision.

Utility of a Triangulation Basis in Civil Engineering.—Mr. Borden, in making his careful triangulation of Massachusetts, considered that one of its most valuable uses would be to serve as a basis for the work of civil engineers and land surveyors, who would thereby attain a high degree of precision in extended surveys, as well as a means of connecting independent surveys together with almost absolute certainty. Accordingly, for the use of surveyors, etc., he not only computed the geodetic co-ordinates, or latitudes and longitudes, but gave rectangular co-ordinates from convenient reference points. It is obvious that these data are more simple and better adapted for the use of civil engineers, while over limited areas their precision is not sensibly impaired by the curvature of the earth's surface. But his primary stations were too far apart to be conveniently used in this way, and the time had not arrived when the advantage of coordinate determinations would be sufficiently appreciated by civil engineers who had been brought up in less reliable methods. There were a few exceptions, however, including ex-President Doane of this Society, and some of his pupils, who systematically referred their surveys to the co-ordinate axis used by Borden in this vicinity, namely, the meridian of the State-House dome and a line at right angles to it. Some of the extended maps of surveys for the water supply of Boston are similarly referred. At the present time, many town and city engineers, including several members of this Society, have expressed their intention to connect their work in a general coordination, as soon as the secondary triangulation, which is expected as a preliminary to the present topographical survey of the State, shall bring stations within their convenient reach.

Under prevalent methods of surveying, great uncertainty often arises in attempting to re-locate lines where monuments have been lost or displaced; but, if carefully connected with an extended triangulation, the uncertainty disappears, and the work is effectually removed from the arena of dispute and litigation by the certainty with which the controlling positions may be restored from the triangulation stations. In those cities and towns where cadastral surveys are to be undertaken, the advantage of such a basis for the work is obvious. In fact, a continuous survey, for any purpose, extending over a considerable area, can best be rendered consistent with itself and its surroundings by basing it upon an extended triangulation, and bringing it into a general system of co-ordinates.

There is another consideration which should not be overlooked in discussing the amount of preliminary triangulation needed in State surveys. In many populous districts the questions of water supply and sewerage are pressing with great force upon public attention. Surveys are likely to be needed for the investigations called for, involving a higher degree of precision than the limit of cost fixed for the State survey would cover. A true economy would seem to require that as much as possible of the work done should be available for such future exigencies. An exact instrumental triangulation would cost but little more than imperfect graphic work, whose occupied stations would be unavailable for any subsequent surveys, while the computed positions would serve as reliable reference points for all future work.

On the whole, it would seem that a wise view was taken of the proper functions of the General Government when authority was given to the Coast and Geodetic Survey by Congress to furnish State governments with secondary triangulation brought to a sufficient degree of minuteness to meet the requirements of topographic work. With adequate appropriations to sustain the authority thus given, there ought to be no difficulty in solving the question as to where secondary triangulation should end and graphic work commence. A proper co-ordination between the geodosists and the topographers in this respect would diminish the labor and cost of topography while augmenting the precision of its results.

Subsidiary Traverse Work.—A skillful topographer, accustomed to the constant use of the plane table, will not readily admit the need of subsidiary work in which field notes and subsequent platting are required. Upon scales as large as $\frac{1}{10000}$ or $\frac{1}{15000}$ the topography may all be drawn directly upon the plane table. Where streams and roads in wooded regions are to be shown, with all their sinuosities, traversing is resorted to, care being taken to connect the traverse lines as frequently as possible with the triangulation points. By orienting the plane table at each angle and measuring distances with the chain or stadium rod, traverses may be made without resorting to field notes. When, however, the scale is diminished to $\frac{1}{20000}$, or smaller, and a more rapid progress over a given area undertaken, a considerable saving of time is effected by resorting to extra field notes for roads and streams, using a light instrument for angle measurements. The field notes might be dispensed with, perhaps, by using a light and portable supplementary plane table, having, however, sufficient stability to permit a few observations at each point occupied without disturbing the orientation, which might be maintained by using a declinometer or magnetic needle. In this way all objects visible from the line of traverse could be rapidly laid down, and the drawing compared on the ground with the objects represented, an advantage over platting from notes that topographers will appreciate. The light plane tables used for mountain work by some of the topographers of the United States Geological Survey seem adequate for this subsidiary traversing, which might be carried on by the younger members of a party. They will usually find more satisfaction in adopting a larger scale than that of the large plane table sheet, to which their work can easily be reduced by proportional divides when ready for transfer.

HYPSOMETRY.

Besides attaining a general co-ordination of results in two dimensions with a greater degree of accuracy than most commercial maps, constructed from traverse surveys, exhibit in the horizontal representation of surfaces, government surveys are now expected to take the third dimension into account by presenting *vertical relations*. These are best expressed upon the maps by a series of lines corresponding to the intersections of certain imaginary level surfaces with the surface of the country represented. The first or lowest of these surfaces, as adopted by the United States Coast and Geodetic Survey and the United States Geological Survey is that of the ocean supposed to be at rest in the absence of tidal influence. The intersection of the mean sea-level with the land surface, corresponds to the coast line at mean half tide. Imagine the ocean to be raised twenty feet higher, still undisturbed by tides, and draw the new coast line upon the map. Let the ocean be again and again raised, each time twenty feet higher than the last. The successive coast lines thus formed and drawn upon the map would represent lines having the same height throughout, to which the name "contour lines" has been applied in hypsometry. An objection to this name is that it does not convey the idea of equal height, and might be applied with equal propriety to other than horizontal outlines; for example, to a vertical profile, or to the outcrop of an inclined strata, etc. A word given in Greek lexicons, namely isohupes (ισουψης) a compound word signifying equally high, would more nearly express the meaning intended. Other intervals between the successive isohupes might be adopted to suit the circumstances of scale, steepness of slopes, etc. The topographers of the United States Geological Survey show isohupes upon their territorial maps with differences of level from one hundred to two hundred and fifty feet. Upon their surveys of Massachusetts and New Jersey the interval is twenty feet, and the same interval prevails in the topographic work of the United States Coast and Geodetic Survey.

Leveling.—The most accurate known method of ascertaining differences of height is by means of the spirit level, but to carry this method into all the details of a State survey would be far too laborious and expensive, especially where the changes of level are frequent and considerable in amount. It use may generally be limited to the running of a series of check lines across the surveyed area, and establishing thereby a system of bench marks to which levels determined in other ways may be referred.

Bench Marks and Reference Levels.—As in determining the horizontal relations of objects a preliminary triangulation is necessary to fix a convenient number of reference points, so in a hypsometric survey, equal or greater care should be exercised to provide in advance reliable bench marks to which the heights of objects may be confidently reerred. A failure to do this will sooner or later involve the work in confusion. In geodetic operations it is usual to determine the relative heights of all the triangulation stations, by measuring vertical angles or zenith distances from one to another. A fair degree of precision is attainable in this way, the most important vitiating factor being the unequal refraction of the visual ray while passing through air in variable degrees of density. In Massachusetts this method was pursued by Mr. Borden, as well as by the United States Coast and Geodetic Survey, with nearly coincident results, where the stations were identical.

Precision in Hypsometry.—The practical uses to which hypsometric information is applied require even greater precision in height determination than in the horizontal relations of topography. An error in the designated height of a stream at any particular point would be more important than the horizontal displacement of the point to a considerably greater extent. Questions of water-power, for example, would require for satisfactory solution a pretty exact knowledge of the amount of fall in the stream. Indeed, the horizontal displacements of incorrect isohupes would, in general, be far greater in amount than the vertical errors involved. It is seldom in nature that slopes are found so steep as forty-five degrees, or a unit of base to one of height. A slope with a base of six horizontal to one vertical on a road would be considered steep. Here the horizontal displacement would be six times the vertical error, and this ratio increases rapidly as the slope approaches to a level.

Hence the necessity appears for an increased precision in height determinations where the surface of the country is made up of gentle undulations. It is also evident that the instruments used for determining differences of level across a State should be capable of a high degree of precision. Since the alidades usually accompanying plane tables are supplied with vertical circles only reliable for comparatively short distances, the necessity for frequent well-determined bench marks presents an additional reason for carrying on the secondary triangulation with the theodolite, including height determination by vertical angles in advance of the graphic work, as far as the expense limit will permit.

Engineering works already constructed in the older States, more especially the railroads and canals, were usually preceded by leveling surveys made with much care. From these surveys, profiles showing the inequalities of the surface were drawn with the heights marked in feet above some reference or datum level. Upon the profile of a railroad, its gradients and the amount of cutting and filling along the line were established. On the completion of the road, its profile, if well made, would accordingly show the exact rate and amount of its successive rises and falls, and the absolute height of any point above the datum level.

The simplicity of the work, and the obvious necessity for a reasonable degree of precision to avoid ultimate confusion, would seem to warrant the expectation that railroad profiles might be used to great advantage in hypsometry. But, on comparing the profile of intersecting roads, many discrepancies are found, arising partly from uncertainties as to the datum level adopted, and partly from a want of care and skill in the preliminary work.

Fortunately, leveling surveys can usually be carried with much greater facility along the roadbeds of railroads already constructed, than over the uneven original surfaces. Much perplexing uncertainty would be avoided, and the work of a topographic survey greatly facilitated, by the comparatively inexpensive expedient of carrying preliminary lines of level across the State, and across each other along the main lines of constructed railroads. In this way they would check each other, and afford the means of correcting and adjusting all the connecting railroad profiles to a common datum level. These profiles should be connected with the trigonometrically-determined points at convenient places, in order to unite all the data into one reliable system of reference heights.

Where as in many parts of New England, the water power of rivers is fully or in great part utilized, preliminary connections should be made with the surfaces of mill ponds or the crests of dams along manufacturing streams. Here the owners of mills have generally taken measures to ascertain the exact relative height of their own dams and of those above and below them, the value of their water privileges depending upon units of differences of level. In Massachusetts, accurate profiles are in existence of such rivers as the Connecticut, Merrimac, Charles, Sudbury, Nashua, Blackstone, Housatonic, and others. Surveys for the water supply of cities and towns generally include carefully-executed levels of great hypsometric value in the regions thus investigated.

Of course, for connecting all these levels with the mean level of the sea, access must be had to the sea coast, where, to obtain the mean level, observations are needed of high and low water. For great precision, a long series of observations is requisite. These, however, have been made, and bench marks established in many of the ports and harbors along the coast, by the United States Coast and Geodetic Survey.

Plane Table Hypsometry.—Having the preliminary data for location and heights carefully established, the topographer is prepared to take the field with his table, secure from the confusion which would attend an inadequate and uncertain determination of positions and heights. The determination of heights in plane table work is almost entirely by means of vertical angles, the alidade of the instrument being provided, for that purpose, with a small vertical circle. On account of the greater precision required, heights are not, like horizontal determinations, obtained graphically. The angles are instrumentally measured, and the distances being scaled from the map, the differences of level are computed or taken from tables. A more convenient method than either might be found, perhaps, in the use of a specially designed slide rule. Without going into the details of plane table methods, it is sufficient to say that the height of each plane table station having been determined, either before occupation, if located by intersection from other stations, or immediately after, if located by resection or by the three point method, is used in turn to fix the heights of all points determined more or less directly from the new station. If the preliminary work has been properly done, and the topographer is skillful in selecting his points of occupation, he will always have several determined points in view from which he can find with certainty both his horizontal position and its height. Spires, cupolas, gables, chimneys, flag-staffs, remarkable trees, rocks, etc., afford good reference points, and their heights at the top, or at some conspicuous point like a weather vane, etc., having been determined, they also form good bench marks. As fast as positions are located upon the plane table sheets, their heights should be marked and the adjacent isohupes interpolated between them. *This should invariably be done in the field*, not left for future office work, which at best is likely to fail in the critical places where the characteristic expressions are to be brought out. Attempts to make character sketches by conjectural contours of indefinite height are sure to fail if not based upon exact truth. True isohupes, with rare exceptions, are themselves the best character delineators. Auxillary lines with smaller intervals may be interpolated between the isohupes of regular intervals, where some peculiarity of feature would fail to be otherwise expressed, and a skillful topographer sometimes takes the liberty of slightly displacing an isohupe from its theroetical position to secure an expression of nature which the true isohupe would fail to bring out, owing to a certain neutrality due to its arbitrary height, somewhat above or below that of the characteristic feature.

Comparative Utility of the Plane Table.—Enough has been said, perhaps, to show the advantages of the graphic method of representing topographic details when compared with the use of field notes and office platting. A topographer who has become familiar with the use of the plane table cannot easily be persuaded to adopt other methods for his special work. Even under unfavorable circumstances, for example, where the geodetic and secondary triangulation points are widely scattered, and extensive vistas are precluded by numerous wooded areas, he will carry in from outside bases a chain of graphic triangulation, extending it between the wooded patches until he finds a check by coming again to previously determined bases. The accuracy of such work is far greater than can be expected from traversing between the widely separated, non-graphic triangulation stations, especially where directions are referred only to the magnetic needle. Of course, well executed previous surveys may sometimes be incorporated into the work with advantage; as, for example, where accurate maps of the compact portions of cities and populous towns are found. These can usually be reduced to the required scale, and after laying down a few of the principal streets by the graphic methods, the remaining network of streets, etc., can be fitted into its proper place. Much assistance may be derived, in locating railroad lines, especially where the curvature is complicated, by platting the engineer's alignment to the scale of the plane table sheet, and fitting it between points graphically determined. The advantages of the graphic method, especially in the projection of isohupes, would obviously be lost, however, if any considerable part of the work were left to be completed, after leaving the ground, by platting field notes or sketching from memory. Besides the loss of time, there is the large element of uncertainty which usually attends the deciphering of sketch notes after they have become "cold" by lapse of time.

As the success of the portrait painter is measured by his skill in reproducing not only the more striking and familiar features of his subject, but a certain subtle, undefinable expression of individual character, so the topographer is a true artist who brings out upon his map not only the salient contours of the country, but the less apparent though real markings, which reveal to experienced eyes the conflicts of the past between the great sculpturing forces of nature and the rugged resistances which have opposed them, the effective touches in either work of art being applied *in the presence of the subject portrayed*, with a true artistic sense of form and proportion.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers—February 17th, 1886.—A paper by Clemens Herschel, M. Am. Soc. C. E., "On the Work Done for the Preservation of the Dam at Holyoke, Mass.," in 1885, and on some studies for a new stone dam for the same place, was read by the author and discussed.

The paper opens with an account of the Water Power at Holyoke. The charter of the Hadley Falls Company was obtained in 1847, one of its purposes being the building and maintaining of a dam across the Connecticut.

The first dam was intended as a temporary one, to serve as a protection during the erection of a more substantial one below it. It was not able to resist the force of the river, and was carried away a few hours after the gates were closed. The construction of this dam is not known to the author

The second and present dam was begun and completed in the summer of 1849. It is 1,017 feet long. At the ends are abutments of heavy masonry. Between these abutments it is composed of heavy timber crib-work, the surface on the upper side being inclined 21° 45′ to the surface of the river. The timbers are bolted to the rock bottom with about 3,000 one and one-quarter inch iron bolts. The foot of the dam was protected with gravel covered with a mass of concrete. All open spaces were packed with stone to a perpendicuiar height of about ten feet. The graveling in the bed of the river began seventy feet above the dam, and was continued over thirty feet or more of its sloping surface. The fall from the river above the dam to still water below is 59.9 feet, there being a perpendicular fall of thirty feet. The total cost is given at $150,000. The chief engineer was Philander Anderson. The maximum height of water over the dam, from its completion to the present time, has been 12½ feet in 1862. Only ten feet had been provided for in the construction. The dam is built on a ledge of red slate, which in places becomes a hard red sandstone. This dips down stream at an angle of about 30° with the horizontal. In 1868 an examination showed that the fall, aided by logs, etc., had washed out the ledge in front of the dam to a depth of 20 to 25 feet, and had in places worked back under the foot of the dam, partially undermining it. In 1868 to 1870 an apron was built down stream from the dam, its volume far exceeding that of the original dam. It was built of round logs laid so as to form bins six feet square, which were filled with stone to the top. This protected the dam from further undermining, but a new "pool" was soon excavated below the apron, which is now 20 to 25 feet deep at the deepest parts.

The dam then continued to do its work until, in 1879, there appeared a well-defined whirlpool above its crest, and examination soon showed a break through the plank covering at that point. This and subsequent breaks were repaired by means of cribs, made like a box without top or bottom, the under side being cut to a bevel, so that when resting on the back of the dam the upper side would be horizontal. In 1881 there were two new breaks, which again broke through in 1882. There were no breaks in 1883, but in 1884 a large one appeared which could not be covered with the 20×35-crib of 1882. A crib, 40×45 feet, was accordingly built, the whole being completed in 19 days. Details of the operations of setting the cribs and repairing the breaks are given. One serious objection to this method of repairing the dam was the liability to make new breaks in repairing those already made. As the dam was all of the same age, the occurrence of much more serious breaks was probable, and the proper course for the future became a question for earnest consideration.

The first project was to sink cribs on the dam, cut through the covering and fill it with gravel well washed in. Plant was accordingly prepared, and in December, 1884, the work of filling was begun, but owing to the severity of the weather no progress could be made, and the work was discontinued until after the spring freshets. This gave an opportunity for a careful study of the whole subject. This was made by the use of models, the use of which is earnestly recommended by the author as in many cases superior to drawings.

The plan finally adopted was by the use of coffer-dams, to lay bare a space 20×100 feet next the crest of the dam, and remove the covering. Sheet piling was then carefully placed against the up-stream face of horizontal timbers of the crib-work of the dam, so as, with the solid course formed by the crossing of the timbers forming the "bins," to constitute a continuous line of sheet piling lengthwise of the dam. Gravel was then dumped each side of the sheet piling, and washed down until no more could be put in. The covering was then restored, and the coffer dams moved to the next section.

In carrying out this plan, the gravel, *debris*, etc., on the surface of the dam had first to be removed for the placing of the coffers. The plan finally adopted for this was to have divers wash the material into windrows with a stream at 80 to 90 pounds pressure through an inch nozzle. This was then removed by a very small clam-shell dredge. Three divers and the dredge finally cleaned 120 feet of dam in about four days. The author comments on the great value of employing divers in many classes of work under water.

He insists on the use of a check valve in the helmets of divers, and of a telephone between diver and tender. Two divers were lost on the work, one of whom would have been saved by the use of a check valve. After the surface of the dam was cleared, the coffer dams were put in place, and the joints made tight by spiking on planks. With the aid of the floating derrick two coffers could be set in place in one day. Before placing the planks of the sheet piling, the "bins" were dug out, or the stone picked out by hand, as low as the water would permit, this being throughout several feet lower than the old stone filling put in in 1849. With the exception of driving the plank into the old filling about a foot, they were carefully set by hand and well braced against the opposite face of the bin. The bottom averaged from 25 to 28 feet below the crest of the dam.

The gravel for filling on each side of the plank was from a pit about two miles away. It was shoveled into dump buckets which were carried on cars to the work, where it was dumped from the same buckets. The average cost for wages was 46.6 cents per cubic yard, about 15 cents of this being for railroad service. The gravel was washed down as dumped, by water from three lines of hose tapped into the coffer dam. The total amount of gravel put in was about 13,000 cubic yards.

As a result of the work done, further breaks as heretofore understood are impossible or of no consequence; the timbers being encased in solidly puddled gravel, are permanently protected against decay, and the leakage has been reduced to about one-tenth of what it was before the break of 1884.

The first half of the dam was repaired in about three months, the last half in one month, and usually on a work of this sort the author considers triple the speed at the end from that at the beginning, generally attainable. Electric lights were used on the work and proved of the greatest value. No difficulties were encountered in closing the last section, this being perhaps due to the fact that that side of the river had filled in much more than the other shore or the middle part. It was well-known, too, that the leakage of the middle 200 feet of the dam was much worse than the rest. The cost of the work is estimated at about $65,000, including the cost of plant. It cannot be precisely stated, because the repairs of 1884 and the break of 1885 were charged to the same account.

The author deduces the following as the lesson of 1849 to 1886 in the construction of wooden dams: 1st. A wooden dam should never be left hollow, nor should it be filled with stone. Let a row of sheet piling be put in in some proper position, then puddle in gravel. 2d. In crib work two timbers should never be butted over another of the course next underneath. 3d. Never substitute masonry for the frame of the dam next to the abutment. 4th. The back of the dam should be guarded from such abuse as the dropping of 4-ton stone upon it. 5th. The shape of a dam should always be chosen with a view to preventing the excavation of the river bed, and the formation of a pool below the dam. In this connection the author made experiments with models one-twelfth full size to determine the proper form for a new stone dam at Holyoke. The ogee form gave the best solution of the problem A reverse incline is necessary at the foot of the dam sufficient to destroy the acquired velocity of the water, and project it in a horizontal direction parallel to the bed of the stream, or the bed of the stream should be protected. The author learned, while writing this paper, that the Croton Dam is of this form. There is also a dam of an ogee shape in Spain.

March 3d, 1886.—A paper by Fred Brooks, M. Am. Soc. C. E., on "Thermometer Scales," was read and discussed. The author advocates the discontinuance of the use of the Fahrenheit scale for temperature, and the adoption for all uses of the centigrade scale. There are few or almost no obstacles to this course. Conversion tables are abundant; its use is more especially for scientific purposes; national prejudices are not excited; it is independent of other measurements; the centigrade scale is already largely used, and it can be used by any one at once without a date being fixed in advance for its universal adoption.

A paper by H. V. Hinckley, M. Am. Soc. C. E., on "Errors in Railroad Levels" was read. The character of the leveling on the Atchison, Topeka and Santa Fé Railroad having been called in question, the author took measures to check the correctness of the levels by direct search and by checks from intersecting roads and reliable benches. The results are summarized as follows:

Rail Circuit Checks.

No.	From	Via	To	Miles.	Errors in Feet.	Errors. Feet per Mile.
1	Kansas City..	Topeka......................	Atchison.. ...	116	0.006	0.00005
2	Emporia Junc.	No. Topeka and Junction City.	Emporia Junc.	196	0.180	0.00092
5	Pueblo	La Junta and El Moro	Pueblo	246	0.580	0.00236
10	Deming.......	Albuquerque and Mojave	Deming.......	1,862	1 978	0.00106
11	Rincon	Deming and El Paso..	Rincon	218	0.190	0.00087
		Tide Checks.				
3	Kansas City...	A. and P. R. Railroad........	San Francisco.	2,115	2.04	0 00096
4	" " ...	A. and P. R. and S. P. Railroad	Pt. Ysabel	2,150	1.03	0.00048
6	" " ...	Deming......................	San Francisco.	2,347	0.062	0.00003
7	" " ...	"	Pt. Ysabel	1,686	0.948	0.00056
8	" " ...	Tombstone...................	Guaymas......	1,657	3.390	
9	" " ...	El Paso......................	San Francisco.	2,459	0.128	0.00005

Note.—Discussion on the subjects referred to is invited.

Engineers' Club of Philadelphia—Record of Business Meeting, February 20th, 1886.—Mr. J. Foster Crowell presented, in continuation of his discussion of the Interoceanic Canal Question, an exposition of the engineering features embodied in the Nicaragua Ship Canal project in its latest form, illustrated by official maps and profiles of the country, harbors and route, accompanied by detailed plans of the dams, locks and other permanent structures furnished through the courtesy of Mr. A. G. Menocal, the chief engineer of the undertaking.

The paper began with a comprehensive description of the topography of the canal site, the great basin of Lake Nicaragua and the San Juan valley—claiming broadly the adaptiveness of the country to the purpose, and defining the canal location, which, in the author's opinion, has been so contrived as to fully avail of what nature has already done.

He stated that in the limited sense in which the term canal is generally used, it is a misnomer for this work, which is to be "a slack water system of grand dimensions, wherein lake and river navigation, practically unrestricted under the treatment proposed, will constitute $128\frac{8}{10}$ miles, or 77 per cent. of the entire passage between the oceans, while the artificial channels will aggregate but 40 miles, or 23 per cent.; and of these artificial channels, 13 miles were to be made so wide and deep as to offer no objectionable restriction, leaving only 27 miles of confined canal, divided into several separate stretches."

Mr. Crowell then proceeded to describe in detail the location of the line, noting the position of the dams, which were to establish the grand summit level of 144 miles in length, and the disposition of the locks; enlarging upon the peculiar conditions to be met in the several cases, and noting the various provisions for control and discharge of surplus water, and for disposing of the surface drainage at the points where the canals required protection therefrom.

He next exhibited drawings of the locks, of which structures there will be seven, three on the Atlantic side, and four on the Pacific, each 650 ft. long, 65 ft. wide, with 29 ft. of water at least depth—these drawings showing fully the various devices provided for working the gates, filling and emptying the locks, the floating moorings for ships, and the constructive features of the lock chambers; the "rolling gate," 88 ft. in height, designed by Mr. Peary, U. S. N., for the great rock-hewn lock, with 53 ft. lift, was fully explained.

The dam structures, of which there are to be two, were described, as also the culverts, waste-weirs, etc., for taking care of small streams encountered at several points.

The breakwater and jetty system, proposed for deepening and protecting from the swell of the sea the canal entrances, were illustrated by means of charts; the author considering that in view of the harbor in Lake Nicaragua for all purposes of through commerce, and the enlarged prisms of the sea sections of the canal, ocean harbors were not necessary, and if constructed, would now constitute a source of superfluous expense. Mr. Crowell here pointed out the causes which had led in the past to the destruction of the once fine sea harbor at Greytown, but claimed that it would be possible to restore it partly, but sufficiently, if, in the future, a necessity for it should arise

The figures of rainfall, water supply and lockage requirement, were adduced. He stated that the total needs of the canal, to work it to its designed capacity of 32 double lockages per day, would be only $\frac{1}{10}$ of the mean daily flow from the lake, or $\frac{1}{8}$ of the minimum daily flow; and that, in addition to this great surplus of lake supply, the tributary streams would discharge much more than enough water to compensate for leakage and evaporation. The paper concluded with a discussion of the estimate for construction of the entire work, amounting to $65,000,000, including an allowance of 25 per cent. for contingencies—the time required for completing the system ready for service being given at six years—and with a statement of the quality and availability of material for construction to be obtained along the line. The thorough character of the surveys, location and computation were referred to, and the presumptive reliability of the information offered was stated to be exceptionally great.

Mr. Crowell supplemented the discussion by reading extracts from a letter recently published by Mr. Menocal, on the relative costs of operating the Nicaragua Canal and a ship railway, assuming, for the purpose of comparison, the capitalization and volume of traffic to be the same for each; taking the official reports of gross and net earnings of the Suez Canal as the basis for estimating the probable proportion of operating expenses for Nicaragua, and assuming that the operating expenses of the railway, as is claimed by its promoters, would not exceed 50 per cent. of gross receipts; and claimed that the canal under these conditions would earn annually 100 per cent. more than the railway, not taking into consideration the further economic advantages arising from the permanent nature of the canal works, which, if properly constructed, would improve witn age, as against the depreciable character of the most expensive parts of the railway and its appurtenances.

Dr. H. M. Chance described some rather paradoxical phenomena experienced in draining a mine by siphons In the case of a double siphon drawing water from two sumps at different levels, the siphon, upon starting, operated satisfactorily, drawing water from both sumps, but in a few minutes the current in the branch leading to the lower sump reversed, and water was discharged *into* this sump, the main siphon continuing to work as at first. This action seems to be due to the loss of head due to friction, as the water acquires considerable velocity in the discharge by which the efficient head at the lower sump is greatly reduced.

Professor L. M. Haupt deferred his paper on the Delaware Breakwater Harbor until the next meeting, but explained, for the benefit of the members present, a dissected model, showing the condition of the bottom before the breakwater and ice-breaker were built, the position of those structures, the scour and deposits that had occurred, and the work done by the currents in the various zones lying between the several fathom contours. The volumes moved were determined by weight, and important physical results were clearly and intelligibly illustrated. The character of the forces acting in this harbor, were, in the author's opinion, easily and readily determined from the changes which had been produced in the mould of the harbor.

A discussion of the general deductions and remedies was reserved for the next meeting.

Record of Regular Meeting, March 6th, 1886.—The Secretary presented, for Mr. Wm. H. Dechant, a description of a practical test to operate a distant signal by a wire run through a pipe filled with oil.

During last September a distant signal was required to protect a new crossing over the Little Schuylkill Branch of the Philadelphia and Reading Railroad, between East Mahanoy Junction and Tamanend. The distance from the operating office to the semaphore signal post is 1,100 feet, and is part way along a 4 and a 6-degree curve.

Instead of leading the wire through a long wooden box, supported on small pulleys, as is usually done, above the surface of the ground, it was decided to try the experiment of running the wire through a pipe filled with oil, buried below the surface of the ground. A trench, averaging 15 in. in depth, was dug along a carefully laid out line; stakes 8 ft. apart were driven along the bottom of this trench, so that their tops should come to a uniform grade line, which, in this case was about 66 ft. per mile; upon the tops of these stakes the $\frac{3}{4}$-in. galvanized iron pipe was fastened, so as to hold it in as true a position as possible.

A number 15 iron wire was strung through each piece of pipe as they were screwed together, so that it might be used to draw the signal wire through the pipe line after it was all laid. The pipes were all carefully examined and cleaned; a number had to be rejected on account of lumps of iron or galvanizing material obstructing the bore of the pipe. After the pipe was all laid, the $\frac{3}{16}$-in. iron signal wire was stretched out with block and tackle to straighten it and take out all short kinks, and was then pulled through into its proper position in the pipe by the smaller wire that had been strung through during the laying of the pipe; a small brass stuffing box was screwed to each end of the pipe, through which the ends of the leading wire were passed; these stuffing boxes prevent the escape of the oil. The ends of the pipe being thus closed up, it was filled with common car lubricating oil, mixed with about one-quarter part of refined coal oil to keep it from thickening in cold weather; the filling was done through a short upright branch pipe attached at the highest end of the pipe.

The lever, by which the distant signal is operated at the signal office, by the same movement turns four signal boards on the tower, and during the summer the usual counterbalance on the semaphore signal post, adjusted to exert its least weight, would operate the arm on the signal post and revolve the signal boards on the tower; during the colder weather the lubrication is possibly slightly stiffened, so that this same counterbalance barely turns the signal boards in the tower, and must have slight assistance.

The experiment has proved very successful thus far in the severe weather of this winter, and has required no attention since being placed in position.

The apparent advantages of this plan are:

1. A very permanent and lasting arrangement.

2. Freedom from disturbance or accident to the signal wire.

3. Entire freedom from the difficulties caused by expansion, if the pipe is laid below the frost line, and subject to but slight changes caused by change of temperature if laid only one foot under ground.

4. Obviating the necessity to provide angle fixtures to change the direction of the wire around curves.

The difference in cost of materials per 100 ft. is but a trifle, being $5.38 for the pipe plan and $5.42 for the wooden box plan. The difference in labor would depend upon the character of the ground, but in most cases it would be nearly the same.

Mr. J. Foster Crowell exhibited, described, and presented to the Club a model, illustrating the Rolling Lock Gate, designed by Mr. R. E. Peary, Civil Engineer, U. S. N., for the Nicaragua Ship Canal.

Prof. L. M. Haupt continued his paper on Harbor Studies, applying the principles to the harbor of refuge at the Delaware Breakwater. During the past forty years there has been a deposit of over 8,000,000 cubic yards inside the harbor, due chiefly to the checking of the currents by the ice-breaker, which is placed athwart them. The closing of the gap is endorsed, and it is further recommended to remove the ice-breaker, and thus augment the ebb scour. If necessary, floating ice-breakers or caissons may be substituted, but, as a matter of fact, there are but few days in the year when the harbor is encumbered by ice-floes. The damage produced by this structure is very much greater than the benefits it confers. The effects of the breakwater in producing a scour at the gorge, and maintaining a 30-foot channel to deep water—the deep holes scoured by the eddies at the ends of the structure, and the relative costs of various plans, were presented and compared with that of the plan proposed, which it was thought, would produce a much better result at less than one-half the expense. The paper was illustrated by a dissected model explained at the last meeting. The number of wrecks on the Atlantic, between New York and Hatteras, in the past two months, is reported by the Hydrographic Office chart as twenty-two.

Mr. C. W. Pusey described Baird's Distiller, as used in the works of the Pusey and Jones Manufacturing Co., for furnishing distilled water for the men.

Wm. H. Derbyshire described a new double lathe for turning steel-tired car wheels, showing the method of holding the axle at four points, so as to give greater steadiness under the cut. The drivers, adjustable in all directions, and a convenient calipering attachment for bringing the wheels to size, were also shown, as well as the cutting tools, which take the whole face of the tire, including the flange, at one operation.

Mr. F. W. Gordon described a lathe for the same purpose, which resembles, in many respects, the ordinary double-headed wheel lathe. There are two head stocks with face plates, two carriages, etc., for finishing both wheels at the same time. The novel feature claimed for this lathe is the arrangement for supporting the axle on its journals, affording a substantial bearing, close up to the wheels to be turned, and thus permitting heavy cuts and doing true work. The lathe has no live spindles. The face plates revolve in rigid projections from the head stocks. The only duty of the face plates is to revolve the work, and the trueness of the work is said to be in no way dependent on the fit of the face plate bearings. In these projections are substantial chucks, which grip the axle on its journals. The distance from the point of support to the point of cut is thus reduced to a minimum; the journal support permits a much heavier cut than can be taken in centers; the wheel is turned true. The work, he said can be turned out very rapidly, and, when done, is well done.

The Secretary, for Mr. J. H. Harden, called attention to a publication of the Chesterfield and Midland Counties Institution of Engineers, upon Davis' Self-timing Anemometer.

The Secretary presented the following for Mr. James F. Wood: "The Atlantic City Drainage Company has discovered that many of the pipes were put down at wrong grades, and are now engaged in taking them up and relaying them at proper grades." I enclose above slip cut from Philadelphia paper. The only interest in it is the extraordinary fuss they made in the papers over criticisms of their *modus operandi* at Club meeting last winter.

ENGINEERING NOTES.

Proposed Canal from the White Sea to the Baltic.—The Society for Promoting Russian Trade held a meeting a few days ago at St. Petersburg to discuss the question of joining the White Sea and Baltic by a direct canal *via* Lake Onega. The idea dates back to the time of Peter the Great, who was Russia's greatest canal maker. In point of fact, so comprehensive were that emperor's schemes that there is hardly a project realized since, or still advocated, that does not derive its inspiration from him, even including M. Dru's French scheme for joining the Volga and Don by a canal, and the favorite project of various Russian generals for establishing a waterway between the Oxus and the Caspian. The White Sea is already joined to the Baltic by a long roundabout water route, starting from Archangel and running up the Dwina to point near Vologda. Here canals connect it in succession with lakes Kudensk, Belozersk, Onega, and Ladoga, from the latter of which the River Neva runs into the Gulf of Finland and Baltic. This route, however, is nearly 1,500 miles long, whereas the construction of a canal from Lake Onega to the River Onega, running into the White Sea. or again from Lake Onega to Vigozera Lake, and thence into the White Sea, would reduce the distance to nearly one-third. The cost of the proposed canal would be about 7½ million roubles. or £750,000; it would be large enough to allow barges over 100 ft. long and correspondingly wide to traverse it with ease. Of late years commerce has decayed very much in the White Sea, owing to the growing tendency of the Russian population to move south to the Euxine, and the general indifference of the Government to the north. Formerly Russia maintained a large fleet in the White Sea, but the navy was totally abolished a few years ago. If the proposed canal were constructed, it is believed by the Society for Promoting Russian Trade that commerce would revive, and that an impulse would be given to the iron industry of the Onega region. Last year, to appease the clamor that the Moscow press had raised at the decay of Russian power in the north, the Czar sent the Grand Duke Vladimir to visit the White Sea, and the promoters of the canal scheme are endeavoring to take advantage of this to secure the support of the authorities. However, seeing the large number of railways and other public works sanctioned this year, we question whether success will attend their efforts.

Herren Bleininger and Hasselmann, two German chemists, have described a method of making facing materials for inner walls likely to become damp. After drying and grinding the clay, they make a mixture of clay, 91½ parts; iron filings, 3 parts; common salt, 2 parts; potash, 1½ parts: elder or willow wood ashes, 2 parts. The whole is heated to a temperature varying from 1,850 to 2,000 deg. Cent.—3,362 to 3,632 deg. Fah. At the end of from four to five hours the argillaceous mixture is run into moulds, then re-baked in the ovens —always protected from the air—at a temperature of 842 to 932 deg. Fah. The product may be variously colored by adding to the above 100 parts: 2 parts of manganese for a violet brown, 1 part of manganese for violet, 1 part of copper ashes for green, 1 part arseniate of cobalt for blue, 2 parts of antimony for yellow, and 1½ parts of arsenic and 1 part oxide of tin for white. The *Scientific American* says these products resist the action of acids, and are well adapted for sewers, etc.

IRON AND STEEL NOTES.

On the Construction of Tungsten and Iron Alloys.—The following investigation was made with a view of determining the chemical constitution of the compounds of iron and tungsten, employed in steel-making. An alloy of the specific gravity 9.31, containing iron 68.4, tungsten 28.2, and carbon 1.9 per cent., was closely powdered and boiled in hydrochloric acid until the evolution of hydrogen ceased, when the crystalline powder adhering to the surface of the fragments was rubbed off. The metallic powder obtained from several repetitions of the above operation was boiled for several hours in hydrochloric acid, and finally washed with water, boiling potash lye, alcohol, and ether, and heated to redness in a current of hydrogen. The result was about 40 per cent. of metallic residue made up of two alloys, separable by the magnet, while scarcely a trace of tungsten was dissolved. The larger part of this residue—fully 90 per cent.—consisted of light steel-gray grains, perfectly unmagnetic, which are well-formed octahedral crystals, sufficiently hard to scratch glass, but so brittle as to be easily rubbed to powder in an agate mortar. They contain iron from 24 to 31, tungsten 69,83, and carbon 1.4 to 1.6 per cent. When heated in the air the powder burns with a glimmering light to a brown, non-magnetic product, which, when heated in hydrogen, is reduced to tungsten iron, the crystals preserving their form. No iron is extracted by boiling hydrochloric acid.

In order to compare the behavior of this iron alloy with those with other metals, a perfectly unmagnetic ferro-manganese, containing iron 35, manganese 57.6, and combined carbon 5.87 per cent,, was powdered, and oxidized by heating in the air. This was attended with the production of magnetic oxide of iron rendering the whole of the powder magnetic, and after reduction in hydrogen, metallic iron could be separated by the same means. The effect of tungsten in modifying the chemical properties of iron when diffused through it, is very marked. This in the particular alloy under examination was found to be completely unaffected by a solution of chloride of copper.

From their microscopic characters, as well as their low specific gravity—3.688—it is evident that the crystals, in spite of their compact appearance, are actually hollow forms inclosing gases. The magnetic portion of the residue is a blackish grey metallic powder, without distinct crystalline character. It contains iron 68.1, tungsten 27.7, and carbon, 4.1 per cent When heated in air it burns, augmenting about 80 per cent. in weight, and remains magnetic By heating in hydrogen, a tungsten—iron compound—is reproduced, which readily gives up iron by digestion with hydrochloric acid.

The same alloys were obtained by boiling hydrochloric acid from a pig iron, containing 23.5 per cent of tungsten; but the proportion of the magnetic uncrystalline compound is larger than that of the harder tungsten crystals. A highly carburized tungsten steel, containing tungsten 11, manganese 1.49, and carbon 2.15 per cent., gave, on solution in hydrochloric acid, 13.1 per cent. of residue in the form of a fine unmagnetic powder similar in composition to the crystals previously described, while a soft steel, containing tungsten when digested with dilute acid, only left traces of iron containing tungsten. The general conclusion drawn from these experiments is, that tungsten is not actually alloyed with the iron, but exists essentially in a free state diffused through the mass of the softer metal, and preserving its own characteristic properties. The most notable of these, namely, low specific volume, accounts for the circumstance that, in order to produce very hard steel by tungsten, it must be used in considerable quantity, in which respect it is in marked contrast to other hardening agents, such as carbon and phosphorus, which form chemical combinations with iron.

RAILWAY NOTES.

The complaints which have been made against the use of steam on the Birmingham tramways are directing attention once again to the reputed superiority of the cable system. A correspondent in a Birmingham newspaper points out that in San Franciso there are six cable lines covering all the most crowded thoroughfares in the city. The cars ascend steep gradients, as much, in some cases, as 78 ft. in 412 ft., and they turn around corners and even cross each other on the same level without any difficulty. In Chicago, also, the efficiency of the system has been amply demonstrated. In that city there are ten miles of double track, and it is worked from one engine house, where there are four engines of 2,000 horse-power in the aggregate; but only one-quarter of this power is ordinarily used, and this operates 270 cars.

Chinese Railways.—English, American, Belgian, French and German industrials all have their eyes directed upon China just now as a profitable field for railway enterprise. A French syndicate has been formed by the Fives-Lille Company and the bankers who group themselves round the Paris Comptoir d'Escompte. M. de Freycinet has instructed French agents in China to afford this syndicate all possible aid. The indefatigable Krupp, of Essen, the Dortmund Steel Works Company and the Deutsche Bank have formed a German syndicate, which Prince Bismarck will support with all the resources of German diplomacy. An American syndicate has been formed under the auspices of the house of Jardine, Matheson & Co., which is very influential at Pekin. The first line proposed to be taken in hand will run from Nankin to Pekin, and will be about 690 miles in length. A second line in contemplation is one from Canton to Honoi, about 562 miles long. We shall probably hear of a heavy Chinese railway loan before long.

ORDNANCE AND NAVAL.

Important Armor-Plate Tests —An important test of compound armor was made on January 21, on board the Nettle, at Portsmouth. The plate was manufactured on Ellis' compound system, by Messrs. John Brown & Co., Sheffield, and was a sample of a number which are now being made by them for the belted cruisers Orlando and Undaunted, now building at Messrs. Palmer's, on the Tyne; the Australia, building at Messrs. Napier's, on the Clyde, and the Narcissus, building at Messrs. Earle & Co 's, Hull. The plate measured 6 ft. by 8 ft., and was of a total thickness of 10 in. It was fired at by the 10-in. gun, with a Palliser shot of 400 lbs. and 70 lbs. of pebble powder. Notwithstanding the severity of the test, the plate withstood the ordeal very successfully. The deepest indent was not thought to be more than about 5 in. The first and second rounds produced circular cracks, probably extending to the depth of the steel around the points of impact, and a few hair cracks on the surface. The third and final shot produced a crack to the right edge of the plate, which, on subsequent examination, was seen to be through, but only $\frac{3}{8}$ in. in the widest part. A remarkable feature was that the bulges at the back of the plate were unprecedentedly slight—only from $1\frac{1}{8}$ in. to $1\frac{1}{2}$ in high—and that they were entirely free from cracks, as was also all the back of the plate, with the exception of the above-named crack to the right edge.

A New Armor-Plated Ship —The first steel plates of a new armor-plated turret ship, to be called the Trafalgar, a sister ship of the Nile, which is to be built at Chatham, have been laid down at Portsmouth. The pieces of keel consisted of the central flat and vertical plates, forming the basis on which the whole structure of the vessel will rest. The flat keel is in two thicknesses, the lower or outer one being $\frac{3}{4}$ in. thick, and the inner one $\frac{1}{2}$ in., the vertical keel being also of the latter thickness. This latest development in armorclad construction will resemble the Dreadnought in many important particulars. To say that she is an improved Dreadnought will signify little more than that she is a turret ship, that her turrets are built across the middle line of the ship fore and aft, that she will carry larger guns and thicker armor, and, as a matter of course, that she will have greater dimensions, in order that this accession of weight may be floated. So far as her profile is concerned, she will more closely resemble the vessels of the discredited Admiral class than the early turret ships; but, as a matter of fact, the Trafalgar is the first of a distinctly new type of protected fighting ships, and combines modifications of the special features of the Dreadnought and Collingwood class. Take away the barbettes of the latter, and replace them by movable turrets, with a water-line armor belt, and something closely resembling the Trafalgar will be the result, or, to put the subject another way, add a superstructure battery between the turrets of the former, and a rough idea of the new ship will be acquired, differences of size being allowed for. The Dreadnought has a length of 320 ft., and breadth of 63 ft. 10 in., and a displacement of 10,820 tons; while the length of the Camperdown is 330 ft., her breadth 68 ft. 6 in., and her displacement 10,000 tons, the difference of the tonnage being due to the difference in the amount of side armor. As the Trafalgar, on the other hand, is not only intended to carry as powerful guns as the Camperdown, but to be protected by an armored belt, her bulk is necessarily greater than either. In length she will be 345 ft., while her beam will be 73 ft., her mean draught 24 ft., and her displacement 12,000 tons, so that she will be a larger ship than the Inflexible, which is 320 ft. long by 75 ft. broad, with a displacement of 11,400 tons. What engine-power she will possess is not known, as the tenders have not yet been prepared, but she will be fitted for forced draught, and it is expected that she will realize a speed of 18 knots. She will be protected by broadside armor 20 in. in thickness, consisting of steel-faced plates, and this armor, while extending nearly the whole length of the ship, is much deeper than in vessels of the Admiral class. In modern turret ships, the turrets are placed diagonally at opposite corners of the citadel, so as to obtain a simultaneous fire of all the guns ahead or astern, unobstructed by the light superstructures at the ends. In the Trafalgar, there will be no forward and after superstructures, and the turrets, which are to be 18 in. in armored thickness, being built at the middle line at each end of the citadel, will have the advantage of practically unlimited training ahead and astern. These turrets will, of course, be able to fire either directly ahead or directly astern together, but with the great increase which has taken place in the power of the guns the advantage which the battle ships of the Colossus class possess in this respect is more apparent than real. The fore turret will have a range of 45 degrees abaft the beam. and the after turret a range of 45 degrees before the beam, giving each a training arc of 270 degrees. As regards the disposition and range of her turrets, the new ship resembles the Dreadnought, but she differs from her prototype in having a central battery between the turrets carrying eight 5-in. breechloaders, having a fair amount of protection, and a superstructure above, which, together with the battery, extends out to the full breadth of the ship, and on which will be mounted a number of rapid-firing 6-pounder and machine guns. Each turret will contain a couple of 66-ton breechloading rifled guns, for which the weight of charge and projectile has not been settled. The torpedo equipment will be unusually large, as many as seven positions having been appropriated for discharging the Whitehead torpedo. Four will be under water, one at the bow, and the remainder above water on the broadside. It is confidently expected that the Trafalgar, when completed, will be the most formidable armorclad either in our own or in any foreign navy. Some delay has occurred through a want of material, but it is believed that the vessel will be ready for launching in about two years. Four years will probably elapse, however, before she will be ready for the pennant.

BOOK NOTICES

Publioations Received.

Extraots from the Report of the Director of the United States Geological Survey:

——— The Requisite and Qualifying Conditions of Artesian Wells. By Thomas C. Chamberlain.

——— The Topographic Features of Lake Shores. By Grove K. Gilbert.

Bulletins of the United States Geological Survey:

No. 15.—The Mesozoic and Cenozoic Paliontology of California.

No. 16.—The Higher Devonia Faunas of Ontario Co., New York

No. 17.—The Development of Crystallization in the Igneous Rocks of Washoe, Nevada.

No. 18.—On Marine Eocene, Fresh Water Miocene and other Fossil Mollusca of Western North America.

No. 20.—Contributions to the Mineralogy of the Rocky Mountains.

No 21.—The Lignites of the Great Sioux Reservation.

No. 22 —New Cretaceous Fossils from California.

No. 23.—On the Junction between the Eastern Sandstone and the Keweenaw Series on Keeweenaw Point, Lake Superior.

New Ordnance Material and Armor Material in Europe. By Captain William Bixby. New York: *Engineering News* Pub. Co.

Lithographio Chart of Iron and Steel Beam Sections of the New Jersey Steel and Iron Co.

Report of the Operations of the Engineer Department of the District of Columbia. Washington: Government Printing Office

PROCEEDINGS of the Institution of Civil Engineers:

Paper No. 2070.—On the Theory of the Indicator and the Errors in Indicator Diagrams. By Osborne Reynolds, LL. D., F. R. S.

Paper No. 2107.—High Speed Motors. By John Imray, M. Inst. C. E.

Paper No. 2108.—On Construction in Earthquake Countries. By John Milne, F. G. S.

SCHOOL ELECTRICITY. By J. E H. GORDON, B. A. London: Sampson Low, Marston, Searle & Rivington.

The object aimed at by the author is thus stated in the brief preface: "The object of the present work is to give schoolboys a knowledge of electricity, which, however incomplete, shall be of a useful kind.

"For this purpose the work commences with the study of electric currents and Ohm's law, and the teaching is of the same kind as that which I have been in the habit of giving to members of my staff and to men employed in electric light work. At the same time I have given such details of theory as will, I hope, show students that a science of electricity exists, and stimulate them to study it. I have further endeavored to show the intimate connection which exists between electricity and light, heat and mechanical energy."

The book will be found to be an easier introduction to practical electrical work than are most of the text books now in use. To adapt it to the instructor's use, questions are appended to each chapter. It is just such a book as eager inquirers have been demanding for the past two or three years.

ELECTRIC RAILWAYS AND THE ELECTRIC TRANSMISSION OF POWER DESCRIBED IN PLAIN TERMS. By ROBERT LUCE, A. M. Boston: W. I. Harris & Co.

This description in popular language of an important class of inventions will prove satisfactory to a large class of readers. Divested of mathematical formula and of technical terms, except such as are absolutely indispensable to an understanding of the general principles, the book will satisfy a demand which is constantly made for an elucidation of these principles which can be read without laborious study.

The Electric Transmission of Power, the History of the Electric Railway, Electric Railways Abroad, Electric Railways in America, Cost of Electricity, Electricity on Elevated Roads, and Telpherage, are treated successively, and with satisfactory clearness and conciseness.

THE PRACTICAL MECHANIC'S WORKSHOP COMPANION. By WILLIAM TEMPLETON. An entirely new edition revised and enlarged. By WALTER S. HUTTON, C. E. London: Crosby, Lockwood & Co.

The general scope of this book is too well known to require special mention here. The new material relates to Air, Gas, Water, Heat and Steam; Testing Engines and Boilers, Turbines, Strength of Materials, Gearing, Chimneys, etc.

Besides the numerous tables which are always found in such handy collections, this book contains fairly complete treatises on Practical Trigonometry and Orthographic Projection.

DIE PRATISCHE ANWENDUNG DER SCHIEBER UND COULISSENSTENRUNGEN. Von WM. S. AUCHINCLOSS. Berlin: Julius Springer.

This is a translation into German of Auchincloss' treatise on the Slide Valve and Link-Motion. The plates, cuts, and typography are exceedingly good.

TABLES FOR CALCULATING THE CUBIC CONTENTS OF EXCAVATIONS AND EMBANKMENS. (Second edition.) By JOHN R. HUDSON, C. E. New York, John Wiley & Sons.

The range of these tables is made to include widths of road-bed from 10 ft. to 28 ft., and center heights to 50 ft.

The previous edition had become favorably known to engineers for convenience of form and correctness in the results obtained by their use.

VORTRAGE UBER BRUCKENBAU.—Part I. Von DR. E. WINKLER. Vienna: Carl Gerold's Sohn

This work of Dr. Winkler will be gladly welcomed by all engineering students who can read German. The author has been for a long time considered an authority upon all subjects relating to engineering structures, and particularly upon the controverted questions relating to complex framings, continuous girders, and the like.

The present edition is the third. The first appeared under the title of "Theorie der Brücken."

The first part only of the new edition is represented in the present volume, and the discussion is limited to the "external forces" acting upon girders.

Of the three sections into which it is divided, the first, A, deals only with "stationary" and "fixed" loads, on simple girders and on overhanging girders.

Section B, which is the greater part of the book, treats of continuous girders, giving both the analytic and graphic discussion of girders of two, three, four, and, finally of many spans.

Section C treats of bending moments and change of form.

The illustrations are plentifully distributed through the text, and six lithographic plates are placed at the end of the volume. The whole is exceedingly well printed, but upon rather thin paper.

MISCELLANEOUS.

THREE tall chimneys belonging to Kunheim & Co., of Berlin, were lately destroyed by means of gun-cotton. The largest was about 147 ft. high, and 10 ft. diameter at the base. In order that it should fall outwards from the city, the charge of guncotton—about 57 lbs.—was attached in portion to the side next the city, and to the adjacent sides. All three were exploded simultaneously with a magneto-electric apparatus. The chimney, instead of falling obliquely, collapsed vertically, and, on inspection, the four walls of the pedestal were found to have been driven outwards. The bricks were all detached from each other, and nearly all entire, *Nature* says the *debris* was thrown a very little distance. The two other chimneys, treated similarly, fell as was expected, *i. e.*, obliquely away from the city. One of them, in falling, broke in two about the middle.

Emery Mines of Asia Minor.—Although emery stone is found in nearly all parts of Asia Minor, and not unfrequently in the remote and almost inaccessible regions of the interior, where the natural obstacles are too great to offer any inducement to the miner, the principal mines are confined to the districts of Thyra and Aidin. These mines, says Consul Stevens, of Smyna, are the Tchavus, the Hassan Tchavuslar, the Aladjali-Tchiflik and Kourchak, the Halka, the Akdere, and the Gurnush Dogh, There is another mine uear Millassa, the stone from which is brought for shipment to a place on the coast called Kuluk, near the Gulf of Mendalio, and is either shipped direct from that place to foreign markets, or brought to Smyrna in small sailing craft for reshipment. When well picked and freed from unsound ore and rubbish, the emery from the Tchavus, Hassan Tchavuslar, and Aladjali-Tchiflik mines is of good and nearly equal quality. The Akdere stone is not so much sought after, while that excavated near Milassa, the larger part of which finds purchasers in the United States, is of inferior quality, the grain being smooth, and a considerable quantity of magnetic iron entering into its composition. The amount of stone annually shipped from Smyrna to Great Britain, the United States, France, Germany, and Belgium, averages 7,000 tons, the relative quantity consumed in each country being in the order named. The process of extraction is as follows: The mines are opened by wells and galleries, and the stone is obtained in most instances by blasting, gunpowder and dynamite being freely used to extract it from between blocks of marble or masses of granite. The overseers and principal workmen at the mines are Italians, who are paid at the rate of three shillings and sixpence a day, while the native workmen only receive about half this amount. The emery is picked daily at the mines as fast as it can be extracted, in some cases not one-half the quantity being selected. It is then conveyed by camels to the nearest railway station, and from thence to Smyrna, where it is generally picked again previous to shipment. When the mines are situated on heights inaccessible to camels, the ore is brought down to the plains by donkeys, and if the pieces are too large to be carried by camels, they are brought to the station in carts drawn by buffaloes. The mines are worked upon the strength of concessions termed *firmans*, granted by the Imperial Government for a period usually of ninety-nine years, or, in cases where the emery has been found on *nacouf* property, that is property belonging to the Turkish religious institutions, by special permit of the department at Constantinople which administers the *nacouf* estates, and exacts payment to them of so much per quintal. A *firman* or concession during the period it is in force can be sold, transferred and transmitted by inheritance, like other property in Turkey, provided due notice be given to the Department of Mines at Constantinople, and authorization formally obtained.

Snow in Cities.—Paris spent about 220,000f. in clearing away the snow of the 8th and 10th of December last, when the fall amounted to from about 8 to 10 centimeters, or, say, 3 in. to 4 in., and from 6 to 8 centimeters, or from $2\frac{1}{4}$ in. to 3 in About 125 grammes of salt were used per square meter, and is said to cost but little in the total, while it makes a great reduction in the cost of removal of a snowfall. The objections which are made in London against the use of salt are, however, real, the low temperature of the mixture doing much harm to horses. In London, during the snowstorm of the first week of January, some sharp work was done under cousiderable difficulties. The snow began to fall as early as six o'clock on the Wednesday morning, and continued till past twelve, and the principal streets had to be cleansed three times that day. A sharp frost set in subsequently, and in that the Commissioners' trouble consisted. Since the last great storm, five years ago, a vast amount of wood paving had been laid down, and it was very difficult to remove the frost from it. Asphalte, on the contrary, could be thoroughly cleansed in three hours. The committee employed, in the removal of the snow, 1,139 extra laborers, and 1,077 extra carters, besides their ordinary staff of 500 men and 61 dust-sifters and wharfmen; they used six barges and 1,777 horses and carts, and sprinkled iu the streets 7 tons of agricultural salt, and altogether they removed from the streets 6,000 loads of snow. In 1881 they had large vacant spaces on which they could temporarily deposit the snow—in Petticoat Lane, on the Thames Embankment, and in Golden Lane; but these sites were now occupied, and they had to cart the snow to Finsbury Circus, Smithfield, and Letts' Wharf. On the whole, the work was wonderfully well done, and though some of the side streets, with little or no traffic, had been left to the last, it was inevitable that, in so exceptional a state of things, some little inconvenience must be endured. Regent Street was for days a disgrace to the borough surveyor and the vestry. The highways committee of the Islington Vestry did a good deal, but they have a large area to work; 400 men, besides the regular staff were engaged in the work. These were reinforced by sixty able-bodied men from the Islington Workhouse, and on the Monday 640 laborers were employed, in addition to the ordinary scavengers Between Wednesday the 6th, and Saturday the 9th inst., the snow was cleared in twenty miles of roadway and stacked in heaps at the sides. This represented the displacement of over 80,000 cubic yards of snow, and by the Wednesday the snow had been virtually cleared from the entire length of the roadways of the parish. Of the snow which had been stacked in heaps, the dusting aud slopping departments had carried away 4,545 loads, or 9,027 cubic yards. The total expenditure incurred in connection with the work, exclusive of cartage was estimated by the surveyor at £815.

VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CCIX.—MAY, 1886.—VOL. XXXIV.

TREATISE ON THE THEORY OF THE CONSTRUCTION OF HELICOIDAL OBLIQUE ARCHES.*

By JOHN L. CULLEY.

Written for Van Nostrand's Engineering Magazine.

II.

Chapter III.

OBLIQUE ARCHES—HELICOIDAL AND OTHER METHODS.

22. It will often happen in public improvements and in architectural constructions that arches are so located that their parallel ends or faces cannot be placed normal to axes of the arches. Such arches are called *Oblique* or *Skew Arches*, and the acute angle the axis makes with the plan of either face of the arch is the *angle of the obliquity* of the arch.

23. The stability of an arch where the coarse stones or *voussoirs* are constructed in the ordinary manner, with their coursing joints parallel with the axis, is weakened the moment the plane of the arch faces ceases to be normal to the axis. This weakness increases as the angle of obliquity decreases.

24. Thus let Fig. 11 be the plan and elevation of a semi-circular oblique arch, whose coursing joints are parallel to its axis X X. Through H and K draw the perpendiculars H 1 and K 2. The thrust of the arch due to its weight and load would naturally be carried to the abutments in lines parallel to H 1 and K 2. But the triangles H J 1 and L H 2 are each supported by a single abutment. They therefore depend upon the bend and strength of the voussoirs within them and in the body of the arch immediately beyond them, to direct a part of their thrust and stress to the opposite

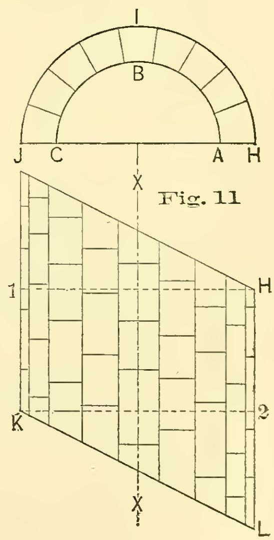


Fig. 11

abutments. Moreover, the thrust and stress thus conveyed must necessarily be in lines or planes other than those parallel to H 1 and K 2, which would cause an outward movement in these triangles, which would be greatest at or near the point J and L. When the angle of obliquity H J 1 or K L 2 is very acute, neither the bond or the strength of the voussoirs will resist the tendency to rupture, nor would the friction of the bedding surfaces produced by the weight and load of the voussoirs prevent the outward movement at J or L, and the arch will fail from sheer weakness.

25. It is true that small oblique arches, with their coursing joints parallel to their axles, are often with safety built. Their stability is due to the fact that as ordinarily constructed the depth of their voussoirs is in excess of what economy would in larger arches dictate. If, however, economy or other consideration should require their depth of ring to be minimum, or if the parts H J 1 and L K 2 were loaded anything like the body of the arch is capable of sustaining, the smaller like the larger arches would give away.

26. It is evident that to maintain the stability of an oblique arch it is desirable that its stress and thrust should be conveyed to the abutments in planes parallel to the oblique faces of the arch, or as near so as is possible, and also that this object cannot be attained when the coursing joints are parallel to the axis of the arch. The coursing beds to fully realize this condition should be normal to the oblique faces of the arch wherever they come in contact with them.

27. There are three methods in vogue that closely approximate this requirement. They are known as the *Logarithmic*, the *Corne de Vache*, or *Cow's Horn*, and as the *Helicoidal Methods.*

Without entering into the comparative merits of these three methods, it will be sufficient for the present purposes to state that the main advantages of the Helicoidal Method are:

The successive coursing beds and joints are parallel to one another throughout their entire lengths, rendering all voussoirs of the same warp in their coursing beds, their soffit and in their extrados; also in their bedding surfaces, except in the arch face. Therefore, all voussoirs of the same length are exactly alike, rendering only one set of templets necessary in their execution—a condition not realized in the other two methods, for both of them each stone is always different from the next one to it in the course. This consideration materially reduces the number and expense of measurements, drawings and templets. For, in the two other methods each stone has its separate and distinct templets, measurements and drawings, and are the objects of much care and anxiety. Thus it is a helicoidal voussoir will fit into any portion of its course, not requiring to be set at a particular place in its course as is required by the other methods. Again, the ring stones at equal distances from the key or center of the arch face, being of the same dimensions this method preserves the pleasing architectural effect of an arch, without the distressing effect produced by the courses increasing or decreasing in size from one side of the arch to the other as is done by the other methods.

28. Whatever may be said as to the stability of oblique arches by the other methods, it is true helicoidal arches with very acute angles of obliquity may with safety be constructed. This acuteness can be considerably less than 30°. John Watson Buck, M. Inst. C.E., places its minimum value at 25°. But it is probable that if the skew backs are maintained in their place that this value is even less.

29. Professor Hyde, in his treatise heretofore referred to, page 101, states that an advantage of this method is that owing to the fact that the coursing joints are parallel, that the courses or whole arch, with the exception of the ring stones, may be constructed of bricks, which is very true. Great caution, however, should be exercised in such construction. The crushing strength of ordinary bricks to that of ordinary building stone is as 1 to 7, and arches never should be built of bricks, unless they are of a first-class, hard burnt quality. This is especially true in public works exposed to the action of the elements. It would be better and safer to recommend that the arches between the ring stones be made of thin coursed rubble of parallel beds, which material is equally adapted to helicoidal construction.

30. Undoubtedly many oblique arches have been thus constructed of brick, either from a want of knowledge of the principles of oblique arch construction, or from erroneous ideas of the excessive cost of warped stone voussoirs over that

of straight voussoirs for the same arch. This excessive cost is but a small per cent. over right arch construction, as will be proved further on. In oblique arch construction brick work is undoubtedly cheaper than dressed stone work, but is not much cheaper than coursed rubble work, while the latter is far more stable, but neither will compare with dressed stone for strength.

HELICOIDAL METHOD.

31. The helicoidal method of construction of oblique arches is one in which the coursing beds of the voussoirs are

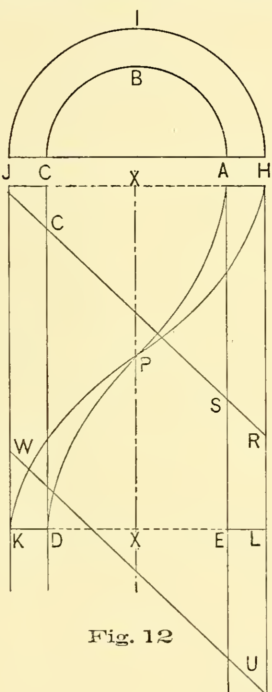


Fig. 12

radial helicoids, whose intradosal and extradosal helices are parallel curves.

32. A helicoid, as stated in article 8, is generated by a right line perpendicular to, and moving on, the axis of the arch as one directrix, and on a helix as the other directrix, and the arch helicoid is that part of this surface generated by that portion of the generating line that is equal to the depth of the arch, and is included between the intrados and the extrados.

33. J W U H in Fig. 12 is the plan of an oblique arch A B C, and H R J equal to K W U is the angle of obliquity, and the helicoid H P K—A P D represents a coursing bed of one course of voussoirs.

34. In the plan of Fig. 13 the extrados is removed in order to show the intradosal helices of the successive courses and the traces 1 2, 3 4, &c., of the helicoids or coursing beds upon the *imposts* A H and C J of the abutments, while in Fig. 14 the traces 1 2, 3 4, &c., and the corresponding extradosal helices, are shown. Were it not for the confusion of

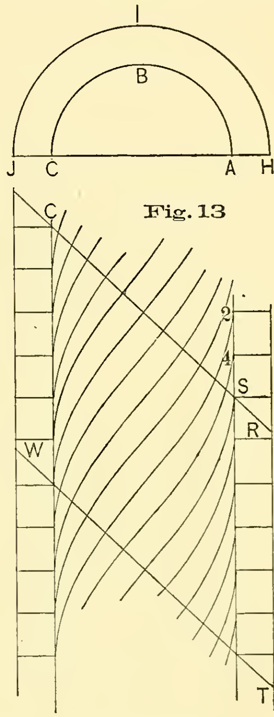


Fig. 13

curved lines, both the intradosal and extradosal helices and the traces 1 2, 3 4, &c., might be given in the same plan, and each helicoid or coursing bed would be shown as in Fig. 12. It should be noticed that the traces 1 2, 3 4, &c., in the face of the impost are elements of the arch helicoids, and are, therefore, normal to the spring lines of the arch, and this is true whether the arch is a full semi-circle or only a segment.

Chapter IV.

THE FOREGOING PRINCIPLE APPLIED TO HELICOIDAL OBLIQUE ARCHES AND DEDUCTION OF FORMULÆ.

35. In the application of the foregoing principles to helicoidal oblique arches a

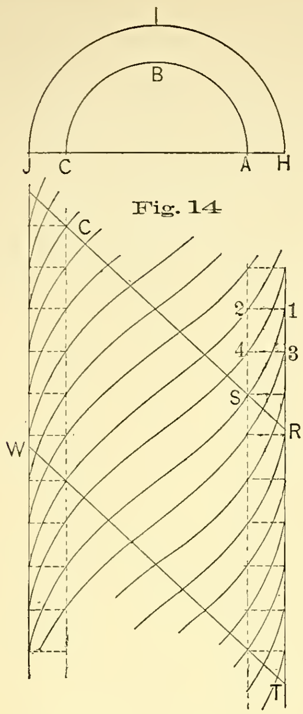


Fig. 14

constant relation is established for any given case between the right diameter of the arch and the length of either the intradosal or extradosal helix of the arch helicoid. In the development of the intrados the helix is drawn perpendicular to a straight line, joining impost extremities of the arch face end of the developed intrados, and, as there is a constant relation between the length of the intradosal and extradosal helices, the construction would also establish a constant relation of the diameter of the arch to the length of the extradosal helix.

Again, it should be observed that since the skew face of the arch in plan is a straight line, the development of either the intradosal or extradosal arch face ellipse will be a curved line, and that the straight line in the development joining the impost extremities of the ellipse will divide this curve line into equal curves.

36. Thus, let A B C – H I J (Fig. 16) be right section or elevation of an oblique arch, and S C V U the plan of its intrados. Draw A G equal to the semi-circumference A B C perpendicular to A E and divide A G and A B C into the same convenient number of parts of equal length and draw the straight line G S. It is evident that the middle point of the ellipse S C in the plan will, in the development, be the middle point of G S. Then, through the points of division in A B C and A G draw lines parallel with A E, and through the points of intersection S C draw lines parallel with A G, the points of intersection of these lines the parallel with A G, with the corresponding lines parallel with A E, drawn through the points of division in A G, will be points in the curved line S X′ G.

Through S draw S F perpendicular to the straight line S G. S F will be the development of the helix S D, whose cylindrical length is S E, and from S F and S E the curve S D may be obtained according to article G. The angle F S E equal to S G A by construction, is the *angle of the intrados* and is designated by β.

37. In Fig. 16 the intrados and extrados of the arch are shown in plan, elevation and in development. The extradosal helix R K is determined from the intradosal helix S D by drawing through S and F, S R and F M perpendicular to R L and to M N and joining R and M by R M. Then R M will be the development of the helix R P K, whose cylindrical length R L equals S E of the intradosal helix S P D. From R L and R M the curve R P K in the plan can be obtained in the same manner that S P D was. Also the curved end R X′ N is projected in the development similarly for H N and H I J as S X′ G was from A G and A B C. The angle M R L is the *angle of the extrados* and isdesignated by β'.

38. Let r be the right radius of the intrados; r' the radius of the extrados, b the depth of the arch, and θ the complement of the angle of obliquity. Then πr=A B C=A G, and $\pi r'$=H I J=H N. Then the relation of the diameter or radius to the helices will be obtained from the following formulæ:

$$\text{A S}=2\,r \text{ tang. } \theta=\pi\, r \text{ tang. } \beta \qquad (8)$$

$$\therefore \text{ tang. } \beta=\frac{2 \text{ tang. } \theta}{\pi} \quad . \quad . \quad (9)$$

This eq. is true and β bears this relation to θ so long as S F is normal to the straight line S G. Sometimes it will be necessary to alter this relation of S F and S G, so that S F will pass through a given point in U Q. This alteration is always slight, and eq. (9) can readily be corrected for it.

$$C\,S \cos.\ \theta = 2\,r, \text{ or } C\,S = \frac{2\,r}{\cos.\ \theta} \quad (10)$$

$$G\,S \cos.\ \beta = \pi\,r, \text{ or } G\,S = \frac{\pi\,r}{\cos.\ \beta} \quad (11)$$

Again $(E\,F = \pi\,r) = S\,E \text{ tang. } \beta$,

$$\text{or } S\,E = \frac{\pi\,r}{\text{tang. } \beta} = \frac{\pi\,r'}{\text{tang.} \beta'} = \frac{\pi^2\,r}{2 \text{ tang. } \theta} \quad (12)$$

reference to these axes, will be obtained in the following manner:

Let 2 be any point in S P D, whose ordinates are x and y, the angle 3 X B be a, and n be the quotient of the length of the arc B 3, divided by the length of the semi-circumference A B C, then

$$a = n\ 180°, \quad x = r \sin.\ a, \quad \text{and } y = n\,S\,E$$

$$= n\ \frac{\pi^2 r}{2 \text{ tang. } \theta} \therefore r = \frac{x}{\sin.\ a} = \frac{2\,y \tan.\ \theta}{n \pi^2 r} (15)$$

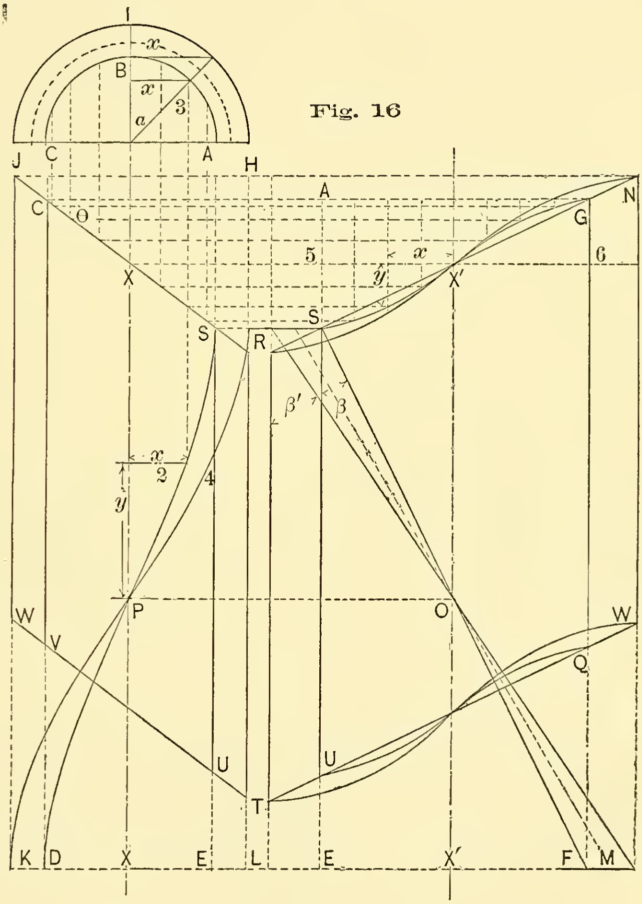


Fig. 16

$$S\,F \sin.\ \beta = (E\,F = \pi\,r) \text{ or } S\,F = \frac{\pi\,r}{\sin.\ \beta} (13)$$

$$R\,M \sin.\ \beta' = (L\,M = \pi\,r') \text{ or } R\,M = \frac{\pi\,r'}{\sin. \beta'} \quad (14)$$

39. In Fig. 16, let X X be the axis of y and P O that of x, with the origin at P, and the equation of the curve S P D with

(15) is the equation of the curve S P D, so that if either x or y is given, n and y or x can be obtained. It is also the equation of the plan of the normal helix to S P D at P, when y equals the nth part of the normal helix's cylindrical length, or n K I in Fig. 2.

40. To determine the equation of R P K let x and y be the ordinates to any point

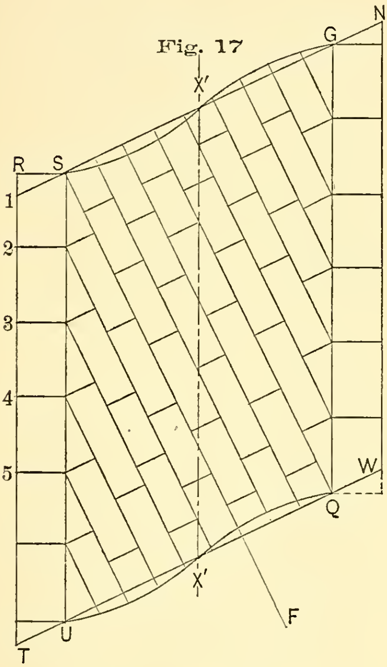
4 in it, referred to same axes as in article 39. Then, as before,

$$y = n\frac{\pi^2 r}{2 \text{ tang.}\theta}$$

but $x = r' \sin. a = (r+b) \sin. a$

$$\therefore r = \frac{2\, y \text{ tang. } \theta}{n\, \pi^2} = \frac{x}{\sin. a} - b \quad (16)$$

41. To determine the equation of the end curve S X′ G of the development with reference axis 5 X′ 6 of x, draw n



through X′ parallel to A G and axis of y X′ X′, let x and y be the ordinates of any point y in S X′ G. Then by reference to Fig. 16 it will appear

$$x = n\, \pi\, r \text{ or } r = \frac{x}{n\, \pi}$$

$$y = r \sin. a \text{ tang. } \theta \text{ or } r = \frac{y}{\sin. a \text{ tang. } \theta}$$

$$\therefore \frac{x}{n\, \pi} = \frac{y}{\sin. a \text{ tang.}\theta} \quad (17)$$

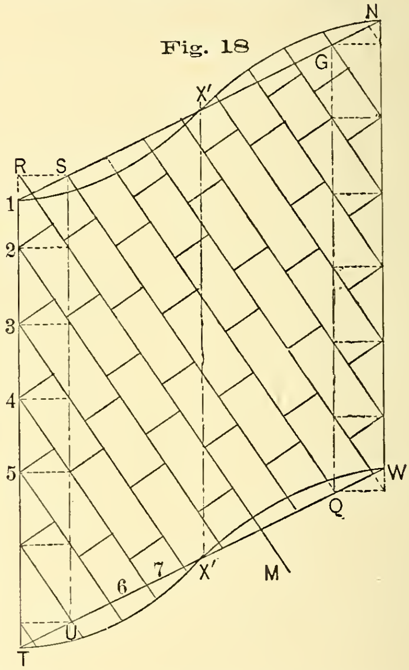
42. And for the corresponding extradosal end curve R X′ N we have as in 41

$$x = n\, \pi\, r' \text{ or } r' = \frac{x}{n\, \pi}$$

$$y = r' \sin a \text{ tang. } \theta \text{ or } r' = \frac{y}{\sin. a \text{ tang. } \theta}$$

$$\therefore \frac{x}{n\, \pi} = \frac{y}{\sin. a \text{ tang. } \theta} \quad (18)$$

43. It should be noted that for a given angle a the points 2 and 4 and 7 and 8 are in lines perpendicular to the axis of the arch. Also that in practice it will be impossible to make full-sized drawings of of the curves S P D, R P K, S X′ G and R X′ N for their entire lengths. The four equations above will be useful in exactly determining any portion of either one of them, and be of great assistance in laying out the work for construction.



44. In a properly constructed arch the resultant of all faces acting upon it should be confined within the middle third of the depth I B of the arch.

When S F in the development is perpendicular S G R M cannot be perpendicular to the line joining the impost extremities of arch face ends of the developed intrados. If then for any reason it is desirable to alter the direction of S F it should be so altered whenever practicable. The dotted line midway between S F and R M (Fig. 16) should approach to or become normal to the straight line, join the extremities of the development of the middle line of the face of the arch shown by dotted line in the elevation midway between A B C and H I J.

45. In intradosal development the coursing joints are laid out in the following manner. Let S U Q G (Fig. 17) be the intradosal development of an arch, and let R T and N W be the outer edges of the extradosal development. Through S draw S F perpendicular to the straight line S G. Divide the straight lines S G and U Q each into an odd number of parts of equal length in order to show a key in the arch face. If S F should not pass through one of the points of division in U Q the length of the arch should be increased or decreased, or altered the direction of S F as indicated in the last article, so that it will pass exactly through one of the points of division in U Q. Then draw lines through the points of division in S G and U Q parallel to S F. The portions of these parallel lines between the ends R G and U Q will be the intradosal coursing joints of the successive courses in the development. The soffit face between them may then be divided into convenient lengths, as shown by drawing their heading joints at right angles to them.

46. Let 1 T W N, Fig. 18, be the corresponding extradosal development to Fig. 17, showing the springing edges S U and G Q of the extrados. Through S draw S R perpendicular to S U, and lay off the spaces R 2, 2 3, 3 4, &c., Fig. 17, on R T. Then through R draw R M parallel to R M, Fig. 16, or as altered by Fig. 17, and through 2 3 4, &c., and the corresponding points in N W, draw lines parallel to R M. Then divide the remaining spaces of straight lines 1 N and and T W into equal parts equal to the distance 6 7 on T W, and through the points of division draw lines parallel to R M. These parallel lines will be the extradosal coursing joints in the development.

VENTILATION.

From "Nature."

In modern life, with its enormous populations living under artificial conditions in towns and cities, the subject of ventilation, or the supply of sufficient pure air to each individual for the maintenance of health, has assumed, as it has become more generally understood, a vast and national importance. Its importance has been clearly demonstrated in many instances by a greatly diminished death-rate in places where overcrowding on space or in houses, formerly existent, has been remedied, and especially by a decrease in those diseases which are now generally recognized as preventible. Thus, since attention has been paid to the amount of cubic space and the supply of fresh air per head in barracks, the death-rate from phthisis or destructive diseases of the lungs in the army has fallen from 10 to 2 per 1,000; and typhus, formerly very prevalent in the gaols of the country and in the crowded courts of our large cities, is now almost unknown in these situations. That there is still a vast amount of disease and death which could be prevented by a more general recognition of the absolute importance of a pure supply of fresh air under all conditions, is a fact whose truth we recognize when we observe the numbers of scrofulous and ricketty children and consumptive adults in our large centers of population. Many houses in the poorer parts of towns are absolutely debarred from obtaining fresh air and light by their surroundings. Built almost back to back, or fronting into narrow courts or passages closed at one or both ends, the sunlight never penetrates for months in the year, and a free current of air is an impossibility. Fortunately the Legislature has recognized this evil, and the Acts known as Sir Richard Cross's and Torren's are intended to remedy such a state of things, and, where enforced, have succeeded in removing buildings which no structural alterations could improve. The erection of huge blocks of Industrial Dwellings, whilst affording vastly superior accommodation to the working classes, has not always secured efficient ventilation in these respects for certain of the tenements. We have seen instances of lofty blocks being built in such a way as to enclose a narrow and well-like court, in which the atmosphere is always stagnant, and from which the inner rooms derive all their light and air. Cottage buildings, with sufficient space in front and rear, are far preferable to lofty blocks placed in rows; but as they do not house the same number of people for the space occupied in crowded districts, where land is of such enormous value, the rents must necessarily be higher, the other accommodation being the same. The air of enclosed courts is often damp, and being stagnant allows suspended particles to fall and foul gases to accumulate in it, thus forming a suitable "nidus" for the growth and cultivation of such disease germs as are capable of existing in the air. It is true that the death-rates appearing in the reports of many of the Industrial Dwellings Companies' are exceptionally low, but we must remember that a very large proportion of the working classes die in hospitals and not in their own houses, and such sources of error require to be very carefully eliminated. Of late years artizans' dwellings have been built on better principles, the experience derived from the sanitary failures of certain of the earlier erections having been taken to heart.

In the model by-laws of the Local Government Board it is provided that no new street is to be less than 36 ft. in width, that the frontage of any new building not standing in a street shall be at least 24 ft. in width, and that there shall be an open space at the rear of any new building and belonging to it of an aggregate extent of 150 square ft., this space not to be in any case less than 10 ft. wide, and if the height of the building exceed 35 ft., to be not less than 25 ft. wide. If these rules could be always enforced in the cases of new buildings, an improvement would be gradually effected in and around towns in the poorer districts which is greatly needed.

From what has been said it will be seen that one of the principal points in any system of ventilation is that the air to be admitted into a building should be pure, and this can be ensured if there is no impediment to the free circulation of currents of air on the outside. We come now to the second part of the subject, viz., the vitiation of air that is constantly going on in inhabited places from the respiration of men and animals, and from the combustion of gas, lamps, and candles, and the methods by which this vitiated air may be replaced by pure external air. The composition of the atmosphere is as follows in 1,000 parts: nitrogen, 790.0; oxygen, 209.6; carbonic acid gas, .4, and traces of ozone, ammonia with nitrous and sulphurous acids in the air of towns, and a variable amount of aqueous vapor. The air taken into the lungs of a human being has this composition, but that expired differs from it in the following particulars, the nitrogen remaining the same: the oxygen which is the vital principle of air is diminished 4 per cent., the carbonic acid is increased 4 per cent., the expired air is saturated with aqueous vapor and is heated nearly to the temperature of the body, 98° Fahrenheit, and contains a small proportion of foul, decomposing organic matter, which exists partly in the form of vapor and partly as solid suspended matter (epithelial dust and scales). This organic matter. though small in amount, is the most injurious quality of expired air, giving to the atmosphere of an ill-ventilated room its close and disagreeable smell. Those who are familiar with the interiors of courts of law, with the pits and galleries of theaters, or with crowded buildings generally, are also familiar with the headaches, the lassitude, and the "malaise" produced by breathing for some hours a vitiated atmosphere. In analyses of such air nearly ten times more carbonic acid has been found than is normally present in the outer air, and when this excess is known to mean a deficiency in oxygen and a corresponding excess in organic vaporous exhalations and suspended matter from the breath and bodies of the persons present, the foul nature of the atmosphere can be realized. The slow deterioration in health, which results from the constant breathing of foul air, is one of its most important results, and causes a predisposition to, and lessened power of, resistance to attacks of disease.

An adult man of average size takes in and breathes out, when at rest, about 30 cubic inches of air at each respiration, this act being performed about seventeen times in a minute, so that in one hour about 17 cubic feet of fresh air will have been vitiated to the extent of containing

4 per cent. of carbonic acid—that is to say, about .7 cubic foot. Such a man gives out when at rest, therefore, nearly .7 cubic foot carbonic acid gas per hour. Now it has been found by Dr. De Chaumont, by chemical examination of a large number of samples of the air of inhabited rooms, that the amount of carbonic acid in the outer air being .4 per 1,000, no close smell is perceived in the air of a room until the carbonic acid reaches .6 per 1,000, or exceeds by .2 per 1,000 that in the outer air, the close smell being always due to the foul organic matter in the impure air, which increases *pari passu* with, and is therefore estimated by the amount of carbonic acid present. It has been assumed by De Chaumont, and experience has fully confirmed this assumption, that we can breathe with immunity air vitiated to this slight extent, but that we should not allow any greater vitiation. We may take it, therefore, that the object of ventilation is to supply sufficient pure air to a room to prevent the carbonic acid rising above .6 per 1,000, this quantity being known as the limit of respiratory impurity. It may be asked why should not the air of our rooms be as pure as the air outside? No doubt this would be desirable, were it not that it involves a continual renewal of the inner air by the outer, which means in cold weather an unceasing draught at an unbearable temperature. We have seen that an ordinary adult man expires .7 cubic foot of carbonic acid in in one hour when at rest, now if such an individual were enclosed in an air-tight chamber, 10 feet high, 10 feet wide, and 10 feet long—that is to say, in a chamber containing 1,000 cubic feet space—in one hour the carbonic acid in this chamber would have had added to it .7 cubic foot of carbonic acid; the air originally contained .4 parts of carbonic acid in 1,000 parts, so that after one hour it would contain $.4 + .7 = 1.1$ parts of carbonic acid per 1,000 or $1.1 - .6 = .5$ parts per 1,000 above the permissible limit for health. But if the subject of our experiment were enclosed in a room containing 3,500 cubic feet of space, in one hour the amount of carbonic acid would be only $\frac{3.5 \times .4 + .7}{3.5} = .6$ per 1.000, *i. e.*, the limit would have just been reached, and at the end of a second hour, to keep the carbonic acid to this limit, another 3,500 cubic feet of fresh air must have been allowed to enter the room. That is to say, an adult man requires when at rest 3,500 cubic feet of fresh air per hour; a woman or child requires proportionally less. For any individual above twelve years of age, we may take as an average the amount of carbonic acid expired per hour as .6 cubic foot, and for such an average individual 3,000 cubic feet of fresh air per hour is necessary. We can now appreciate the importance of cubic space, for if we are to supply 3,000 cubic feet of fresh air to every individual above twelve years, in a room, and the amount of space, suppose, in a dormitory where ten persons sleep is only 300 cubic feet per head, then 30,000 cubic feet of fresh air must be supplied per hour—that is to say, the air of the dormitory must be completely changed ten times in this period, a proceeding which would cause in any but the very warmest weather a very disagreeable draught. But if the cubic space per head be 1,000 feet, then the air of the dormitory need be changed only three times per hour, and if such renewal be effected steadily and gradually no draught need be felt. We may mention here that a certain amount of superficial or floor space is necessary for each individual, for if the height of the room is much over 12 feet, excess in this direction does not compensate for deficiency in the other dimensions, although the cubic space may be the same; thus it would not be the same thing to allow a man 50 square feet of floor space in a room 20 feet high, as to allow him 100 square feet of floor space in a room 10 feet high, although the amount of space allotted to him in each case would be the same. It may be interesting here to mention that in common lodging-houses under police regulations, 240 cubic feet of space are allotted to each adult, in barracks about 600 cubic feet, in general hospitals about 1,000 cubic feet as a rule, and in infectious fever hospitals from 1500 to 3,500 cubic feet—in these latter institutions the floor space allowed per bed is from 150 to 300 square feet. From the report of the royal commission on the housing of the working classes it would appear that even the low allowance of the common lodging-houses is very often not attained in the crowded room.

of tenement houses, and an enormous number of cellars are still inhabited in our large towns, although they presumably come up to the requirements of the Publich Health Acts as regards their ventilation.

Gas, candles, and lamps use up oxygen and produce carbonic acid and water. A cubic foot of coal gas produces, when burnt, 2 cubic feet of carbonic acid, and since a common burner consumes 3 cubic feet of gas in an hour, it produces 6 cubic feet of carbonic acid in the same period. Therefore, as much air should be supplied to dilute the products of its combustion as would be necessary for three or four men. It is far better, however to use such gas lamps as are shut off from the air of the room. These receive the air necessary for combustion from without, and the products of combustion are carried off by a special channel to the outer air. The electric light uses none of the oxygen of the air and gives off no carbonic acid nor water, rnd is for these reasons far preferable to naked flames for lighting purposes.

Ventilation is said to be carried on by natural or by artificial means. In the former are included (1) diffusion of gases; (2) action of the wind by perflation and aspiration; (3) movements caused by differences in weight of masses of air at different temperatures. By the latter, although the same principles are involved, is meant exhaustion of air by heat or by steam from apartments or propulsion of air into such spaces by mechanical means, as fans. Diffusion causes a rapid mixing of different gases placed in contiguity; thus the gaseous impurities of respired air mix with the fresh air in a room until homogeneity is established. Diffusion, however, does not affect the suspended matters which tend to fall in a still atmosphere. Consequently organic matters which exist principally as minute solids in a state of suspension in the air, are not affected or removed by diffusion. The wind when in motion causes a partial vaccum in the interior of tubes, such as chimneys and ventilating shafts placed at right angles to its course. The air in these tubes being thus partially aspirated or sucked out by the action of the wind, to restore the temporary vacuum so made, air from below rushes up to take its place, a continual current in a perpendicular direction being thus set up. Perflation by winds is the setting in motion of masses of air by the impact of other masses. This action is illustrated when the windows on opposite sides of the room are fully open. The room is rapidly and continually flushed with air, an enormous effect being produced, for it has been estimated that the air of such a room may be renewed many hundred times an hour, even when the movement of air outside is only two miles an hour or 1½ feet per second, equivalent to a very gentle and almost imperceptible breeze. Such a method is of unquestionable utility for rapidly changing the air of an unoccupied room, and may be generally put in operation in summer in inhabited rooms when the temperatures outside and inside the house approximate. In any system of ventilation that depends entirely on the wind there is always the difficulty of regulating the velocity of the current according to the amount of movement of the air, and during complete calms the action is nil. For ventilating the hold and interiors of ships at sea, the wind may be most advantageously utilized. A cowl placed so as to face the wind conducts the air below, whilst another reversed so as to back to the wind allows the used air to escape.

The movement due to masses of air at different temperatures is the natural force chiefly relied on for ventilating the interior of houses. The air of inhabited rooms in this climate, except in warm summer weather, is at a higher temperature than the outer air; hot air is lighter than cold air, and will rise for cold air to take its place—in fact, heated air is displaced upwards by colder and denser air. In a room as usually constructed with sash windows, with a fire-place and chimney, but without any special means of ventilation, when a fire is burning in the grate the heated air of the room in part ascends the chimney-flue, and in part rises to the ceiling. Cold air from outside will then enter, if the windows be closed, under the door, under the skirting boards, between the sashes of the window, and through any other chinks or apertures due to loose fittings. The bricks and plaster of the walls are also porous to a slight extent, and if not covered with paint or wall paper will admit air to a limited extent. Thus a large volume of air may be entering a room in cold weather when the fire is burning although there be no visible inlets, and the amount of air thus supplied may be sufficient for the needs of two or three persons if it were properly distributed. But such is not the case. The cold air, which enters chiefly near the floor, takes as straight a course as possible to the fire-place, producing a disagreeable draught to the feet of the occupants, whilst the heated and vitiated air near the ceiling is left undisturbed. It has been found practically that to prevent draughts, and to insure a thorough distribution, fresh air should be admitted into a room above the heads of the occupants, an upward direction being given to it, so that it may impinge on the ceiling, mix with, and be warmed by, the heated air in this situation, fall gently into all parts of the room, and be gradually removed by means of the chimney-flue or any other outlet. The inlet openings for fresh air now most in use are intended to serve this purpose. For sash windows Hinckes Bird's method, now so well known, of placing a solid block of wood under the lower sash of the window so as to raise the top of the lower sash above the bottom of the upper, admits the air in an upward direction to the ceiling above the heads of the occupants. Holes bored in a perpendicular direction in the bottom of the upper sash, louvered panes to replace one of the squares of glass, an arrangement for allowing one of the square of glass to fall inward upon its lower border and providing it with side cheeks, or a double pane of glass in one square open at the bottom outside and at the top inside—all effect the same purpose and are simple and inexpensive contrivances. Wall inlet ventilators, as the Sherringham valve and Tobin's tubes, are constructed on the same principles, fresh air, which in towns may be filtered through muslin or cotton wool, or made to impinge upon a tray containing water so as to deposit its sooty particles, being admitted at a height of about 6 feet from the floor and directed upwards towards the ceiling. The usual outlet for vitiated air is the chimney-flue, and this for an ordinary medium-sized sitting-room, with a fire burning, is sufficient for three or four people, provided no gas is alight, or the gas lamp has its own special ventilating arrangements. With an ordinary fire, from 10,000 to 15,000 cubic feet of air are drawn up the chimney in an hour. Valves placed so as to open into the flue near the ceiling are sometimes used as outlets for foul air, such are Neil Arnott's and Boyle's valves, which permit air to pass into the flue, but prevent its return; the only objections to their use are that they occasionally permit the reflux of smoke into the room, and their movements backwards and forwards cause a slight clicking noise. In all new buildings where efficient ventilation is desired, it would be preferable to construct a shaft at one side of, or surrounding the chimney-flue, with an inlet near the ceiling of the room and the outlet at the level of the chimney top, so that the air escaping from the room would have its temperature kept up by contact with the chimney, thus aiding the updraught, whilst the risk of reflux of smoke would be avoided. In all new domestic buildings a very great improvement might be effected by providing for the warming of the air before its entry into the apartments. The window and wall inlet ventilators just described are occasionally productive of draughts in cold weather, so that it is more usual to find them closed or stopped up than in action, or else admitting a very insufficient supply of air; but if the air be warmed before admittance to an agreeable temperature a very large amount may be allowed to enter without the fact being known to the occupants. The ventilating stove invented by Captain Galton, the Manchester school grate, and other forms effect this purpose in the following manner: Behind the grate, which is lined with fire-clay, is a chamber into which fresh air is admitted by a pipe from the outside. The air, here warmed, is admitted into the room by a pipe opening at about the level of the chimney breast and guarded by a grating which can be opened or closed as found convenient. In the Manchester school grate the warmed air is admitted by vertical pipes, like Tobin's tubes, opening on a level with the chimney-piece. The danger in these grates is that cracks may be formed by the heat of the fire in the joints or in the cast-iron plates which surround the air chamber, and thus direct communication be established between the grate and air chamber with the result of deleterious products of combustion being admitted into the air of the room.

When the stove is lined with fire-clay there is no danger of the air in the chamber being overheated, producing charring of the organic matter in the air and an offensive smell, which is often noticed around stoves where this precaution has not been taken. In Mr. Saxon Snell's ventilating thermhydric stove the fresh air is warmed by passing over hot water pipes in the stove before entrance into the room, the hot water being derived from a small boiler at the back of the grate. The temperature of the water is not high enough to overheat the air.

Gas is being gradually introduced for heating purposes, and with a reduction in its price we may look forward to its its more extended use. There are several ventilating gas stoves by which air is admitted into a room warmed after passing through the stove. It is important to regulate the heat carefully so as not to overheat the stove and the air which is passing through. In churches and other public buildings air is usually warmed before entry by passing over hot water pipes which circulate around the building under the floor. In all large buildings the combustion of gas may be made a very effective means of getting rid of foul air. It has been found by experiment that the combustion of one cubic foot of coal gas causes the discharge of 1,000 cubic feet of air. In theaters where gas, although being gradually replaced by the electric light, is still much used, the extraction of foul air from the roof of the building by the sunlight burners presents no difficulty. The difficulty experienced is the introduction of fresh air from below without causing draughts. In private houses the use of an extraction shaft over the gas chandelier, or a Benham's ventilating globe light, or a Mackinnel's ventilator, greatly aids the extraction of foul air from the ceiling, and is then directed horizontally by flanges so as to be distributed over the room. Outlets in the ceiling of a room may become inlets when a strong fire is burning, as the draught up the chimney will overbalance the extractive power of the gas and cause all other openings into the room to be inlets. We may here mention an ingenious method for warming the air admitted by Tobin's tubes into a room: a row of small Bunsen burners encircles the tube at its foot, and the products of combustion are conveyed away by a tube which surrounds the Tobin and opens into the outer air.

In large public buildings, where expense is no object, a combined method of ventilation by propulsion and extraction presents many advantages. The amount of air admitted can be easily regulated, warmed, cooled, or moistened, and freed from impurities by filtration, and enormous volumes are capable of being so supplied by propulsion and removed by the extractive powers of a furnace. In the Houses of Parliament where this system is in operation, air is propelled by rotatory fans along conduits to the basement, where it is warmed in winter by passing over steam pipes, and then passes upwards through shafts into the space beneath the grated floor of the House. The heat can be regulated by covering the steam pipes with woolen cloths, and in summer the entering air can be sprayed with water or cooled by passing over ice in the conduits. The vitiated air in the House passes through a perforated glass ceiling in the roof, and is then conducted by a shaft to the basement of the Clock Tower, where it passes into the flue of a large furnace.

The introduction of electricity for lighting and of gas for heating purposes will, in the case of both public and private buildings, considerably modify the methods of ventilation now most generally used.

According to Messrs. Moss & Co.'s "Steamship Circular," "the anticipation that a very considerable reduction of tonnage would be shown when the returns of the output for 1885 were made up, has proved correct. Statistics are briefly thus: Tonnage built in United Kingdom, 1883, 1,250,000 tons; 1884, 958,000 tons; and 1885, 540,000 tons; or a reduction of 750,000 tons on the output of two years since. This should have a serious effect on the value of steam shipping, and if, as seems very probable, the output of 1886 will be even lower than 1885, we may then reasonably hope that the excessive over-production has been fairly checked, and that supply and demand will be more evenly balanced."

ELECTRICAL TRANSMISSION OF POWER.

By CHAS. J. VAN DEPOELE.

From "The Telegraphic Journal and Electrical Review."

During the summer months of 1885 I entered into a contract with the directors of the Toronto, Ont., annual exhibition, to run a train of three cars and a motor car from the street railway terminus to the upper grounds of the exposition, a distance of a mile. Having only a single track, I had to prepare here for a light train and good speed. The plant consisted of the following:

One steam engine, 10 by 16, running 125 revolutions per minute, driving an ordinary 40-light (arc) machine, having an E.M.F. of about 1,400 volts and an intensity of current of about 18 ampères. The engine and dynamo were placed in Machinery Hall, close to the boiler room.

The dynamo was connected, one pole with the rails, which were fastened together by means of fish plates, and the other pole to an overhead wire, hanging over the center of the track, by means of arms extending from poles placed along the length of the track. On the top of the car, on which the motor wâs placed, was a contact wheel carried by a pivoted beam, the latter being provided with a spring on one end pressing the wheel at the other end up against the underside of the overhead wire. This contact wheel was in communication, by means of a flexible cable, with the switches, rheostat and motor; from the motor the current was carried to the axles of the wheels, the wheels to the track, thus closing the circuit upon the generator.

We began placing poles, &c., on September 1st, and made our first trip on September 5th. From beginning till end not the slightest hitch occurred, running regularly from 8 A.M. till 10.30 P.M. without stopping a minute. On many occasions we carried from 225 to 250 people. One end of the track we had a 200 feet curve to start, then a level of some 2,000 feet, with two curves of about 1,000 feet radius, then a grade of some 1,500 feet, gaining gradually to about 6 per cent. The rest of the road had a downward grade to the terminus, which made it a disadvantage in starting. As above said, the distance was a mile, and the round trip never exceeded eight minutes, so that, including starting and stopping, we made for part of the way at least 30 miles per hour. During the last five days of the fair we carried 50,000 people. The consumption of coal, as given by Doty & Sons, who ran the engine, was on an average of 1,000 lbs. in 10 hours.

The next step was to South Bend, Ind., where we eqipped four ordinary street cars, one large open car with a 10 H. P. motor, and the other three closed cars each with a 5 H. P. motor. The large car was run for the first time on November 14th, 1885, and was packed with humanity to its utmost capacity. Everything worked like a charm. The plant consists at present of the following:—A 50 H. P. water wheel, and two 20 H. P. generators, and, as above stated, one 10, and three 5 H. P. motors. The track is laid with the ordinary flat rail, so in order to connect the rails together we placed copper plates 3 inches by 12 inches under the joints and spiked the rails down on both sides of the track, so that there is no chance of breaking circuit. As will be understood, the rails in the present case form again one part of the circuit, the other part consists of a copper wire $\frac{1}{4}$-inch diameter suspended above the track, from cross wires fastened to poles placed near the curbstone, and at a distance of about 100 feet apart. From the under side of this copper wire or conductor hangs a carriage, fastened to a flexible cable, passing to the inside of the car, where it is in connection with the switches, the motor, &c.; this carriage travels along with the car, and makes a perfect contact. After the first trial of November 14th the 5 H. P. motors were soon in place and have worked admirably. The tracks are never perfectly clean, on account of constant traffic over the road, but since both rails are connected and also all four of the wheels, it is almost impossible to break circuit between the motor and the rails. The cars have run right along through mud and snow, and no trouble has been experienced with the circuit.

On running the four cars at once, the generators work perfectly, from 6 in the morning until 11 P. M., requiring not the slightest attention; the brushes are set in the morning, and are not touched afterwards. Every car works independently, back or forward, without interfering with the others; the division of the current leaves nothing to be desired. The only trouble we have encountered with the plant has been with some small mechanical details, such as link bolts breaking, &c. These, of course, being small matters are easily remedied. The main point here was the electrical part, and this has proved to be an unqualified success.

The length of the present road is about $2\frac{1}{2}$ miles. The other roads will be equipped as soon as the weather allows of the placing of the poles for the cross wires.

On the 6th day of October, 1885, we entered into a contract with Mr. McConnico, President of the New Orleans Exposition, to run a train of cars in the grounds, with a carrying capacity of from 180 to 200 people. This road is similar to the one in Toronto, nearly a mile long, running from St. Charles Street main entrance, along the Government buildings through the grounds, to the main building and Art Hall.

All was ready for operation for the opening day, but on account of delay in obtaining steam power, we only began running regularly on December 14.

The heaviest work we have done, so so far, is in Minneapolis, Minn., and that during the winter months when snow and ice are faithful companions on the track; whether invited or not, they are there, and never fail.

Before undertaking the job, I was very much afraid that electricity would not be practicable in a climate where the thermometer rises seldom above the freezing point for at least three months of the year. All my fears, however, have been removed in the past six weeks; we have ascended the grades and turned the curves with at least as much facility as the steam dummies.

The electrical plant consists at present of one 60 H. P. generator and a 50 H. P. motor. Our circuit consists of the rails for one side and an overhead copper wire $\frac{3}{10}$-inch in diameter for the other side.

In South Bend we have water power as the prime motor. We ran for the first time on New Year's Eve, 1885, and continued on New Year's Day. The water wheel had no governor, and we found it rather dangerous for the generator. As the water wheel had to be governed by hand, it was impossible to keep the speed anywhere near constant. It was decided to put a governor on before running regularly. Several trips, however, were made over the entire length of the road, giving entire satisfaction. The weight of motor is 3,500 lbs., and the total weight of motor car or electric locomotive is 8 tons. The passenger cars in use here are similar to those on the New York Elevated. In some instances we had three to four inches of solid ice on the track and broke our way through it without the least trouble; in a few days the water power will be in shape to run regularly, when we will run on schedule time.

Thus far we have demonstrated that electric railroads can be operated anywhere where the steam motor can go, and that there is much in favor of the electric motor in cold countries is very evident; there is no danger of pumps freezing up, nor of breaks becoming inoperative; no water tanks are needed along the road, nor is there any coal to be taken; in fact, there are thousands of advantages in the application of the electric locomotive on street and other railroads. Whenever water power is obtainable the economy need not be disputed, and even in the case where steam is to be used as a prime motor there will be considerable economy.

No cheaper or better plant can be expected to run light trains on suburban roads than the electric motor; as, for instance, in the Detroit road now in progress, connecting the latter city with Dearborn, a single train will be run with six large-sized street cars; the speed will be from 15 to 20 miles an hour, the length of this road is nearly three miles, and it will be in operation in a few weeks.

A similar road will be in operation early in the spring in Appleton, Wis. In this case, however, six cars will be equipped with 10 horse-power motors and run independently; the length of road is about eight miles; the speed about ten miles per hour. Water power will be used to run the generators.

The street railway in Montgomery, Ala., is now being equipped with our motors, twelve cars in all, and will be running within thirty days.

In all the above places we are using overhead conductors, which are no more of an obstruction than the ordinary telegraph and electric light wires; in fact much less, since the conductors are over the center of the roads, so that wherever wires are allowed for other purposes, they cannot be refused for the present purposes. I do not believe, however, that overhead wires would be practical in large cities where other wires have to be buried; but in this case the electric conductors can be placed underground in conduits similar to those used for cable cars. This will be much more expensive than the overhead conductors, but it will be a permanent an practical fixture.

I feel sorry that I have not found more time to prepare some figures with regard to tests of motors and general transmission, but the above is a *résume* from practical experience and facts on the track instead of on paper. I am a solid believer in the saying that experience is the best teacher, and to all the above I have attended personally from beginning to end, and am more than ever convinced that the electrical transmission of power has not only ceased to be ephemeral, but has become a real fact and a blessing to the world. All is ready, it has only to be applied judiciously and success is imminent. Thousands of horse-power are now running waste in our waterfalls which can all be utilized to advantage, in some cases running our tramways, in others our factories, &c., giving at the same time light and cheer during the absence of old Sol.

A NEW SUBSTANCE FOR SUBAQUEOUS FOUNDATIONS.

By E. GAERTNER.

Translated for Abstracts of Institution of Civil Engineers.

In carrying out pneumatic foundations an iron caisson of the form of the object required is generally used as a working chamber. The masonry carried up upon this is usually constructed within an iron sheathing, which serves to protect the new work from injury by friction as it is pressed down into the ground, and also acts as a cofferdam. The caisson and the sheathing remain permanently in the structure. Many attempts have been made to lessen the cost of this system, caused by the loss of the iron. Works have been carried out in which the caisson served only as a diving-bell, and was afterwards removed; but this method, apart from its great cost, only answers where the foundation does not go deep into the bottom, and then only for special cases.

In another direction saving of cost has been sought by removing the upper iron sheath after the masonry has been carried up sufficiently high, and using it again.

Already in 1851 Pfannmüller had suggested in a scheme for bridging the Rhine at Mainz that the upper portion of the iron sheaths for the piers should be screwed off when the masonry was carried up above the water-level, and used again at another pier. In the case of the Saltash Bridge, Mr. Brunel removed the iron cylinders, 37 feet in diameter, for the whole depth of about 56 feet, in which the piers were not imbedded in the bed of the estuary. In constructing the Antwerp quays, the contractors built the masonry, which was founded upon pneumatically sunk caissons, within massive iron sheathings, which, when the masonry was far enough advanced, were unbolted from the caissons, lifted bodily, and reused at another part of the wall. As the foundation of the masonry did not go far into the solid, the friction to be overcome in lifting these sheathings was not great.

In 1882 the Societá Italiana began the founding of a quay-wall, about 220 yards in length, along the corrected course of the Tiber for the protection of the Villa Farnesina. The work was all done in the dry, the great curve of the Tiber not being cut out till later. The wall was founded upon a series of iron caissons, 65 feet 7 inches long, 15 feet 9 inches wide, and 29 feet 6 inches deep. The masonry was brought up for 23 feet in rough tufa and puzzuolana-mortar, and for the remaining 6 feet with a facing of travertin blocks.

A sheathing of unusual construction, which was put up to its full height at once, was used, perhaps, rather as a protection during the sinking for the rough masonry in slow-setting mortar, than as a cofferdam in which to build the upper masonry. This sheathing consisted of vertical iron plates 23.6 inches wide, connected together by two flat bars riveted together, between which the edge of the plates was pushed. There was no filling or caulking of the joints, and no attachment to the caisson. When a length of walling was finished, the plates and bars were pulled out and used again in another length.

Inspired by these works the author designed a "foundation mantle," which easily takes to pieces, and is adaptable to any form of caisson. It consists of vertical plates, 0.2 inch thick and 2 feet 7 inches wide, in 6 feet 7 inches lengths, joined together at the horizonal points by double coverplates and a double row of bolts. Laterally these plates are kept in position by fitting in a riveted ⌶ formed of two bars, 5.9 inches$\times$0.47 inch, separated by a bar, 2 inches$\times$0.27 inch, all three being riveted together. The vertical plates are not fastened to these ⌶ irons, but the joint is caulked. The ⌶'s break joint with the plates, and are only lightly attached to the caisson.

In the winter of 1883–4 the two abutments and two piers of the bridge over the Wisloca at Dembica, in Galicia, were erected upon this plan. The area of the ofundation of the abutments is 68 square yards each, and of the piers 57 square yards. The foundations varied in depth from 20 to 26 feet below low water, and from 28 to 37 feet below the ground level, and four or five rows of the movable plates were used according to circumstances. The materials sunk through were sand gravel first, and lower, stiff clay. When the foundation of one pier was completed and the masonry brought up high enough, the sheath was removed to the next pier. It was used four times.

To obviate any danger of bolt-heads or rather projecting pieces catching on the masonry as it is being drawn out, the space between the sheath and the masonry is filled with sand as the latter progresses. The sheath is removed by windlasses, which draw out the vertical plates and fish-joints one by one. The joint between the sheath and the caisson is simply broken in this operation.

The weight of the sheath, including all joints and fastenings, is for the lowest row of plates 19 lbs. per square foot, and for the rest 15.6 lbs. If the plates have to be re-used over a caisson of different shape from the one from which they are being taken, it may be necessary to bend them to the required curve, and to this end they must be of the best material; the vertical fish-joints are the same for all shapes of caisson.

It had been intended to make careful tests to ascertain the amount of friction encountered in drawing off the sheath, but the floods of June, 1884, made it necessary to get the work done as soon as possible, and the tests were therefore confined to the right pier, which was 115 feet from the bank, and founded 21.6 feet below low water and 38 feet below the surface of the ground, made up of—

Sand and clay.............	10.50 feet.
Loose stones and sand.....	18.60 "
Firm clay.................	8.90 "

While the sinking of one of the caissons was in progress, the giving way of the joints of two of the vertical plates at their joining with the caisson, gave the opportunity of calculating the external friction, the bottom of the caisson being at the time 5.2 feet below low water, and 23.3 feet below the surface of the ground. This gave a resistance due to friction of 5.1 tons per foot run of circumference, equivalent to 492 pounds per square foot of surface of the sheathing.

These and some observations of other plates which gave way on the further sinking of the caisson, taking into account the degree in which they followed the caisson or stayed behind, showed that the earth-pressure on the inside of the sheathing is proportional to the friction just as is the case on the outside.

These slight observations showed that the coefficient of friction inside is at least as great, if not greater, than that outside, and that therefore passive earth-pressure produces as great an amount of friction as active earth-pressure. It was now of interest to determine the resistance to friction when both surfaces of the sheathing were sliding, as is the case when the sheathing is drawn off, instead of only one as in the former cases, and whether, as must be theoretically assumed, the resistances work simultaneously on both sides of the plate, and are thus proportional to the sum of the inner and outer coefficients of friction. If this is so a comparison of the theoretical calculated outside friction with the observed resistance to the drawing up of the sheathing should show the former to be at most one-half the latter.

The calculations have been made for all the cases in which the plates were above water (there being no theory giving useful results for material permeated by water).

The theoretical earth-pressure was determined by Rebhann's Construction in which the weight of the material was taken at 98.3 pounds per cubic foot, and the angle of repose for sand with loam at 38°, and gravel and sand 36°. After a long series of observations the coefficient of friction for the outside was found to be 0.466, and for the inside 0.588, or 20 per cent. greater than the outside friction. The results of the calculations were reduced to diagrams which thoroughly proved that with the simultaneous action of two surfaces of the same body (as in the case of the sheathing when being drawn off), the resistances to friction act simultaneously on the two surfaces, and therefore must be added together.

a.	*b.*	*c.*	*d.*
Depth below Surface of Ground in Meters.	Mean Resistance to the Wind'g up of the Vertical Plates of the Sheath'g.		
	Per Plate 2 Feet 7 Inches Wide.	Per 1 Meter of Circumference of Sheathing.	Per Square Meter of Sheathing.
	Tonnes.	Tonnes.	Kilograms.
1.0 (3.28 feet)	0.140 (0.138 ton)	0.177 (0.053 ton per ft.)	177 (36.3 lbs. per sq. foot.)
2.0	0.560	0.709	354
3.0	1.390	1.759	586
4.0	2.620	3.316	829
5.0	4.560	5.772	1,154
6.0	5.550	7.025	1,171
6.5	6.290	7.962	1,224
6.75	7.290	9.227	1,367
7.10	9.150	11.582	1,631
7.50 (24.6 feet)	11.310 (11.13 tons)	14.316 (4.295 tons per ft.)	1,908 (391.1 lbs. per sq. ft.)

The above table refers to the land pier on the right bank of the Wisloca. From this table it is seen that the friction at considerable depths, and especially where the earth is saturated with water, increases very rapidly. The mean water-level in the case of the pier to which the table refers was about 4.7 meters (15.4 feet) below the surface of the ground. The observations and calculations described in the paper were made by Mr. Adolf Titze, who was the engineer in charge of the works on behalf of the firm who built the bridge, the author of the paper being a member of the firm.

THE INJURIOUS EFFECT OF A BLUE HEAT ON STEEL AND IRON.*

By C. E. STROMEYER, Assoc. M. Inst. C.E.

From "The Engineer."

It was stated that, in spite of the many excellent qualities possessed by mild steel, and in spite of its extended use for shipbuilding and for marine boilers, many engineers considered it a treacherous material. They were able to adduce numerous instances in which steel plates and bars had failed, in their opinion, in an unaccountable manner. In nearly all such cases a cursory examination brought out the fact that the plates in question had been subjected to bending or hammering while hot, and there could be little doubt that while they were being worked these plates were at a blue heat, or as smiths and boilermakers termed it, a black heat. It should by this time be well known that such treatment was the most injurious to which steel could possibly be subjected, and therefore such failures could not be properly regarded as unaccountable. Iron possessed the same peculiarity, but being less ductile than steel, similar failures were not so glaring

The author then mentioned cases in which plates, both of iron and steel, had failed without this treatment, although the quality of the material was good, according to the usual tests. Three hundred and thirty experiments had been made in connection with the subject of the paper, and consisted mainly of bending and of tension tests. The results were contained in tables and in diagrams.

It appeared that the limit of elasticity of both iron and steel was raised by repeated tension testing. In some cases the limit rose above the original breaking stress, although the ultimate breaking stress was only slightly affected. The total elongation was reduced by previous mechanical operations, while the contraction varied considerably. A test piece which had been shortened when cold showed a reduction of the elastic limit, but another piece which had been shortened when hot showed an increase.

By the expression "blue heat" the author meant to include all those temperatures which produced discolorations (ranging from light straw to blue) of the surfaces of bright steel or of iron.

The author showed that steel which had been bent cold, either once or twice, would stand almost as many subsequent bends as the original test pieces. But if the same material was bent once while blue-hot it lost a great deal of its ductility. Out of twelve samples, in which two preliminary hot bends were made, nine broke with a single blow of a hammer, and the other three only stood one or two subsequent bends. Thin Lowmoor iron did not break quite so easily, but supported about one-half the original number of bends. The following Table contained some of these results:

	Medium Hard Steel $\frac{3}{8}$ in.	Mild Steel. $\frac{3}{8}$ in.	Very Mild Steel. $\frac{3}{8}$ in.	Lowmoor. Iron. $\frac{3}{16}$ in.
Unprepared or annealed..........	21	$12\frac{1}{2}$	26	20
Broken hot (blue)........................	$2\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	3
1 preliminary hot bend.......	3 mean	$2\frac{1}{6}$ mean	11 mean	12 mean
2 " " bends........................	$\frac{1}{3}$ "	$\frac{1}{3}$ "	$\frac{2}{3}$ "	10 "
1 preliminary cold bend........................	20	$9\frac{1}{2}$	—	—
2 " " bends........................	$19\frac{1}{2}$	$8\frac{1}{2}$	19	13
4 " " "	—	—	13	11
8 " " "	—	—	15	6

* A Paper read before the Institution of Civil Engineers on the 16th of January.

The experiments all pointed unmistakably to the great danger incurred if iron or steel were worked at a blue heat. The difference between good iron and mild steel seemed to be, that iron broke more readily than steel while being bent; that iron suffered more permanent injury than steel by cold working, but that if it had successfully withstood bending when hot, there was little probability of its flying to pieces when cold, like mild steel.

It was a common practice amongst boilermakers to "take the chill out of a plate" if it required a little settling, or to set a flanged plate before it was cold. This was nothing else than working it blue hot, and should not be allowed. All hammering or bending of iron and steel should be avoided, unless they were either cold or red-hot. Where this was impossible, and where the plate or bar had not broken while blue-hot, it should be subsequently annealed. It was satisfactory to learn that, since the introduction of mild steel, a practice had been gaining ground amongst boilermakers, which must have the effect of guarding against such failures, and should be encouraged. It consisted in the cessation of work as soon as a plate, which had been red hot, became so cool that the mark produced by rubbing a hammer handle or other piece of wood over it, would not glow. A plate which was not hot enough to produce this effect, yet too hot to be touched by hand, was most probably blue-hot, and should under no circumstances be hammered or bent.

The theory, that local heating of a plate set up strains which sometimes caused failures, did not appear to be supported by the experiments. But it was doubtful whether the proposal to locally reheat a plate, which had been worked when hot, in order to anneal this part, should be carried out. Several test pieces were made red-hot or blue-hot, and then were slowly cooled, by holding one of their edges in cold water. As might have been expected, the medium hard steel lost much of its ductility. The other steels and the iron were not greatly affected, as would be seen from the following Table:

	Medium Hard Steel	Mild Steel.	Very Mild Steel.	Lowmoor Iron.
Unprepared or annealed	21	$12\frac{1}{2}$	26	20
Quenched red hot in boiling water	24	10	—	—
" " cold water	1	10	19	20
Red-hot, quenched edge in cold water	3	8	25	27
Blue " " "	3	$6\frac{1}{2}$	19, 19	21, 14

The author concluded by suggesting that the question should be further investigated, and that steel manufacturers should endeavor to ascertain whether every quality of steel was made permanently brittle by being worked at a blue heat, or whether this was independent of the various impurities contained in it; and also whether prolonged exposure to a blue heat could produce the same effect.

In a letter in reply to an epistolary communication of certain arguments as to the dimensions and relative distances of molecules advanced by Mr. Jules Bourdin, and published in *La Lumière Electrique*, Professor Clausius says, that the mean path of the molecules, multiplied by eight, is to their diameter as the total volume occupied by the gas is the volume occupied by the molecules; and that if the gas departs from the law of Boyle and Gay-Lussac, the departure is due to several causes, one of which is that the volume actually occupied by the molecules cannot be neglected as compared with the total volume of the gas. In order to explain the propagation of luminous waves across space, it is requisite to admit the existence of a matter susceptible of more subtle division than the ponderable gases.

THE MASSACHUSETTS DRAINAGE COMMISSION.

ABSTRACT OF THE REPORT OF A COMMISSION TO CONSIDER A GENERAL SYSTEM OF DRAINAGE FOR THE VALLEYS OF THE MYSTIC, BLACKSTONE AND CHARLES RIVERS.

Sewerage may be defined as the removal of what is popularly called filth, by water. For the purposes of this report it has been found convenient to consider household sewage, and the pollution of bodies of water by manufactories, separately. Confining ourselves, then, more particularly to domestic sewerage, it may be said to be largely an outgrowth of the modern systems of water supply. So long as people live thinly scattered over the country, no difficulty arises about the removal of the offensive refuse of living. It is sufficiently solid to be retained in suitable temporary receptacles for a season, and readily taken away from time to time to land, where it is valuable as manure. As long as the natural supply of clean water sufficed for the community, so long the simple natural channels of absorption and diffusion were able to carry it away when made dirty by use. Even after the inhabitants in towns became closely packed together, the same methods could be made to answer by enlarging the vaults into cesspools. It is still retained in many large places, but it requires great care in management, and considerable expense to prevent nuisance. Speaking generally it is found easiest and cheapest to use water as a vehicle for entire removal. Especially is this accepted as almost inevitable when the use of water becomes as lavish as it generally does in our towns when once a public water supply is introduced. Systematic water supply turns "night soil" into mere dirty water, which can hardly be carried away in carts, or permitted to leach away through the ground. It calls for a channel of discharge as swift and capacious as its source of supply. Sewerage works are, so to speak, the corollary of waterworks, and, in our opinion, should immediately follow their adoption everywhere. Take the city of Boston for an example, on a large scale, of what is done in miniature in half the larger towns in the State. The Mystic and the Sudbury are turned through the city at the rate of thirty million gallons a day. This enormous flood is used, and turned to sewage in the using. It must then be got rid of; but how? To answer this question in each case is the science of sewerage. The simple and obvious way is to let it run into the nearest water. This is the practice of the earliest time, and it is still admitted to be the best where it is entirely practicable. For, earnest as has been the protest of many noted theorists against this apparent waste, yet a great preponderance of evidence has convinced the best modern authorities that the loss is not a real injury. Not that any one denies that human excrement is a good manure. Nor can we controvert the chemist when he offers to prove that every ton of Boston sewage contains two cents' worth of fertilizing matter. Admitting it all, the difficulty of extracting it remains. Practically, no one would take the sewage of Boston as a gift, although in theory it may be a mine of wealth. The truth is, that the excreata and other valuable ingredients are so mixed with heterogeneous and often injurious matters, so altered by chemical changes and so drowned in water, that that they are of little or no value. It costs more to get them out than they are worth when saved. Taking all the accessible evidence into account, the very able and distinguished royal commission which lately discussed the whole question of sewage disposal in connection with the great problem of the London sewage, came at last to the conclusion that "in some very favorable cases a profit may be made without purification, and very frequently the purification may be made without profit; but the two cannot apparently be combined."

Still, though it may be true that the simplest and easiest may yet be the best way of getting rid of sewage, it is not always suitable or safe. For, though diluted so much as to be valueless, it is not diluted enough to be harmless. It retains a facility for decay which makes it an offensive and a dangerous neighbor, and that, too, whether we cast it into the sea, or into estuaries or rivers or brooks. The defilement is often such as to cause alarming mischief. It may answer very well for New York to discharge her sewers directly into the Hudson and East River on either hand, or for St. Louis to drain straight down into the Mississippi at her feet, or for Chicago to lead her sewers into the lake under her very nose, but Boston found that it would not do to use her harbor, spacious as it is, for a cesspool; and London, after having spent twenty millions to empty her sewers ten miles below her on the Thames, now finds even that remote outlet so intolerably offensive that it must either be pushed on to the open sea, or some means of purification before discharge must be resorted to. Nevertheless, if it can be done effectually and finally, it is undoubtedly cheapest and best to cast the foul water entirely away into a body of clean water so large and so free that all trace of the contamination speedily disappears.

But when the situation does not admit of this disposition—and this condition may result from a lack of a good outlet, as well as from mere distance from the water itself—we are brought to the discussion of the other systems of disposal of sewage which have obtained the greatest degree of acceptance among professional experts and practical engineers.

First among these are two plans for using earth in much the same way as we have above described water to be frequently used. One of these schemes insists more upon the manurial value of sewage, the other looks only to its purification. The former is known as Broad Irrigation. By this process, the sewage being conducted to land prepared for the purpose, is suffered to flow over it and be taken up in part by the crops raised upon it. In short, it is an attempt to extract the element of value from the sewage by using it as a fertilizer in farming. The noxious and offensive elements are thus either beneficially appropriated by crops, or are detained in the soil by mechanical filtration, or, by long and repeated exposure to the air are decomposed, oxidized, and changed into harmless matters, so that the water which runs off is comparatively pure. More than one hundred towns in England employ this system, and it proves eminently satisfactory where conditions favor its adoption. Its great drawback is the vast area of land required for its successful operation on a large scale. It is stated, for example, in our engineer's report, that Boston would require a farm about as large as the entire township of Brookline, if it wished to realize the whole farming value of its sewage. The best English authorities estimate that one acre of land must be set aside for each one hundred persons. When it is remembered that this land must all be tolerably level and fairly dry, some appreciation is reached of the obstacle which this incident presents to the general adoption of this system. There are subsidiary difficulties which will naturally occur to all. It suggests alarming possibilities of farming on a large scale, by municipal corporations. This prospect may well damp the enthusiasm of many who would eagerly welcome such a solution of the sewage problem, if sufficient private farming enterprise were available upon tracts of land convenient and adapted to the purpose. If only the farmers stood ready to take all that might come in every hour of the year, the case were simple enough; but here lies the difficulty. This system proper does not contemplate running to waste any part of the sewage. And this circumstance is important because any elasticity just at this point would materially accelerate its welcome in New England. For weeks, and sometimes months, of our summer droughts, this dirty water charged with stimulating substances might be invaluable to men who had learned how to use it to best advantage. But that is not the proffer which we have to make when we lay out an irrigation farm. Dry or wet, night and day, summer or winter, the same quantity must be taken, or, if there be any variation it is likely to be most when the crop needs it least. And it is this obligation which we fancy would dismay our farmers. But in the absence of such a private demand, it is difficult to see how the work can be carried out without the direct intervention of the municipality. Now, there are manifest and weighty objections to superadding such delicate functions to the already onorous duties imposed upon our town and city governments. Even apart from the consideration that they seem already sufficiently burdened, it is not probable that such management could be made tolerably economical in the long run, to say nothing of any profit, but it may be said that such a farm ought to command a rent, if there is really value in sewage. Possibly this may turn out on trial to be the case. The farm at Pullman is asserted to have more than paid expenses at times. but we have no evidence as yet that private capital is convinced of the practicability of making a profit from such a contract, and even if it were, tenants of such farms would require vigilant watching lest they turn away unwelcome sewage into the nearest water-course.

In fine, we believe this system to be admirable, if only a number of somewhat intractable conditions, some of which we have indicated, can be controlled. Where all things can be made to work together in harmony it offers a reasonable probability of at least reducing the expense of getting rid of sewage to a minimum Where an arrangement can be made to operate it in combination with filtration, so that private agriculturists may take the sewage in such quantities, and at such times as they may find best for their crops, and when not desired can turn it upon filter beds, we think there would be a fair prospect of attaining the largest measure of utilization with the least possible complication and expense.

The second of these plans is known as as Intermittent Downward Filtration through porous land. Intermittent filtration, pure and simple, is the converse of irrigation. The latter is the mininum quantity of sewage applied to the maximum area of land, and permits utilization, as well as purification to the greatest degree. The former is the application of the maximum quantity of sewage upon the minimum area of land. It permits of only partial utilization, but in our opinion of more perfect purification. It frankly abandons all dreams of profit, and in so doing it gets rid of the two greatest drawbacks to the system of irrigation. Having no crop to consider, much less land will suffice, as it is found that the ground will filter ten times as much sewage as any crop upon it can profitably absorb. Having no farming ventures at stake, we are relieved of all the machinery of trade and difficulties of management. Purification, not profit, is the paramount idea. Not that it is impossible, in certain cases, to combine some profitable use with this primary intention, but if so, it is a purely secondary consideration. This system is, in effect, nothing but turning certain tracts of suitable land by skillful preparation, into monstrous filters. There is properly no attempt to save any matters held in suspension or solution in the sewage. The object is to get clear of them utterly, whether they be good or bad, precious or worthless, and restore the water to its first estate, pure and undefiled as it bubbled from the spring. And this wonderful transformation is confidently asserted to be brought about by a faithful application of the filtration process. Its advocates maintain that sewage passed through ten feet of prepared earth is good enough for any purpose, and they claim it to be nature's process, and intimate that, after all, it is a mere question of a little more or less remoteness, and every drop of water on earth to-day was sewage not long ago. However that may be, it is sufficient for the present purpose to say that if properly managed it does afford a practicable, economic and efficient means of cleansing sewage. The objections to it are fivefold. It is charged to be wasteful in that it feeds no crop. There is a dread lest so much sewage on so little land should cause offence, especially in midsummer. Doubters are confident that the land must eventually clog. And, finally, it is thought that the cost of the preparation of the land will be excessive, or that the carelessness to be bargained for with ordinary management on a large scale would render its success utterly problematical. The final arbiter of all such questionings is experience, and that infallible test has decided that these fears are for the most part groundless. The first cost of preparing the land is doubtless likely to be considerable, but as so much less land will answer the purpose, there is found to be a large saving on this head over broad irrigation. If thoroughly prepared, the filter will not clog, provided it be used intermittently. And finally, as to management, it has been found possible to insure care enough to avoid all offence in many places in England for many years. To the impeachment of waste it pleads guilty, urging only in mitigation, firstly, that it is entirely susceptible of modification, with a view to partial utilization; and secondly, that it can easily and advantageously be used in combination with farming enterprise, and is indeed an indispensable safety valve of that system in almost all cases. Finally, we ought to notice the prophecies of disaster which have been widely disseminated hereabouts, founded upon the alleged utter incompatibility of either of these systems with the violent extremes of the New England climate.

It is urged with great force that Old England and New England differ too diametrically in their climates to admit of safe comparison. The skeptics point out that England's atmosphere is moist and equable, while our heats are tropical and our cold arctic; that one-half the year our land is frozen solid and the other half baked hard; that in summer the sewage will stink insufferably, while in winter it will freeze into dirty icebergs, which spring will convert into torrents of sludge and filth. Once more we fall back upon experience. At Pullman, where it is colder than in most parts of Massachusetts, the frost never prevents the flow and absorption of the sewage; and the hottest days of July and August the primitive filter-field at Concord is never a nuisance, nor the lawn at the Worcester Hospital an annoyance. The sewage is warm, and melts its own way into the earth when the frost is hardest; and, no matter how hot the air, the earth has a wonderful power of deodorizing and destroying the harmful elements in sewage. This property has been so abundantly manifested in a multitude of instances, here and elsewhere, that we feel that we take no undue risk in dismissing the climatic bugbear as a chimera. We have then no hesitation in recommending the adoption of this system where for any reasons broad irrigation is impracticable or undesirable and the ocean unattainable, and we think it likely to prove always a valuable auxiliary, in combination with irrigation, where the surroundings admit of its introduction.

Processes of Deposition or Precipitation.

There remain to be noticed a number of operations with sewage which are all based upon some application of the principles of deposition or precipitation. By allowing the suspended matter to settle naturally, or by intercepting it by artificial strainers, it is possible to extract a certain percentage of it. But neither of these processes has been yet proved to work well in practice with large quantities of sewage. They are now usually supplemented by chemical treatment. The addition of lime is most generally approved for this purpose, but a multiplicity of other substances has been tried with various success. As a business venture purely, we doubt whether any scheme has proved lucrative. The resultant sludge, however manipulated, does not seem to make a highly-prized fertilizer. But a complete review of the attempts to extract the treasure from sewage would exceed our limits. Our concern is merely to make up our minds whether we ought to advise the trial of any such device upon any part of our territory. Waiving all claims which may be made in favor of these processes, as profitable or at least inexpensive, let us inquire exactly what can be expected from them, and at what cost. And here we can do no better than to condense and adopt the conclusions of the royal commission upon this head, to whose voluminous and exhaustive report reference has been made before. They tell us that "a chemical precipitating process does two things; it effects improvement in the liquid flowing away, and it leaves behind a precipitated deposit which has to be disposed of."

"The main object of a chemical process being to purify the effluent, the first point of inquiry is, to what extent does it answer this end?"

"No one denies that the suspended matters may be almost entirely removed, and therefore the clarification must effect a great improvement." It is also the general opinion that chemical processes in their best form will have some effect in removing noxious matter in solution, but all agree that a considerable amount must be left in the effluent. This, however, may be safely discharged into a running stream, if its proportion to the supply of pure water does not exceed five per cent. But we have still to deal with the precipitate—about fifty grains, we will say, to the gallon. It is very offensive, and not valuable. By subjecting the sludge to methods of pressure, however, most of the water has been expressed without offence, and its weight reduced to about one ton to one hundred and sixty-five thousand gallons of sewage. It is possible that some market value might attach to this residuum in some localities, but we dare not count upon anything better than gratuitous removal. Finally, the cost of the operation in England is estimated to be just about one shilling per head, or, say, twenty-five cents here for each person yearly. This does not include interest on the capital invested in the works, land, and so on. By itself, therefore, it does not appear to be financially attractive.

The processes of precipitation can, like the other methods of disposal which we have briefly discussed, be combined to advantage with some one or more of those others when the circumstances favor or require it. For instance, precipitation may be supplemented to advantage by application to land. The clarified but imperfectly purified water can be used for irrigation, or passed through a ground filter, which effectually and finally removes all trace of taint or stain. By this means all desirable results can be accomplished. In case of towns on tidal rivers, this plan may be resorted to with advantage to clarify the sewage before ultimate discharge. It was somewhat considered in connection with a part of the Mystic system, but it was more expensive than the plan finally adopted, and we have not thought it expedient, upon the whole, to try any of these methods in any case with which we have been called to deal. But it may very possibly prove of service in the hand of the authorities of some towns, who may be searching for a combination which may permit the discharge of a comparatively small amount of partially clarified sewage into estuaries, creeks, or small streams.

To sum up, we are of opinion, upon the whole—

1st. That when it can be done unobjectionably, it is best to throw sewage into great quantities of free water.

2d. That filtration on land, either alone or in combination with one or more of the other processes, ranks next.

3d. That when irrigation is especially favored by circumstances, it is better than either of the preceding; but that it is so seldom that these circumstances can be controlled to advantage, that we assign to it a third place only in practical usefulness.

4th. That precipitation and chemical treatment may be advisable in connection with either of the first, second or third of these devices, but in our present state of knowledge ought not to be preferred to either of them.

Although we have preferred to treat of these fundamental propositions of the science in connection with one branch only of the subject, it is not to be inferred that we are inclined to admit any inherent distinction between household sewage and the pollution of water by other instrumentalities. Chief among these is the contamination caused by the use of water in manufacturing processes, and the incidental damage to the purity of water resulting from the establishment of great industrial activities upon streams and rivers. But while the injury done is not essentially different, there are some peculiar considerations bearing upon this part of our problem which should not be overlooked.

Manufacturing.

Manufacturing industry has from the earliest days been greatly favored by the law-makers of Massachusetts. To foster and encourage it they long ago substantially dedicated the unnavigable running waters of the land to its use. Believing its prosperity essential to the common welfare, the Legislature has not hesitated to step to the very verge of its constitutional power to stimulate and maintain it. For more than half a century persons have been authorized by law to dam up streams, and flood lands of others, for their own private manufacturing ends. This taking of one man's property against his will for the individual benefit of another has been justified as a proper exercise of the prerogative of eminent domain, on the ground of the advantage inuring to the public from the improvement of water power, and the importance of encouraging manufactures. It has been supported, also, upon the principle which permits the State to compel the several possessors of a common interest, which they cannot beneficially enjoy in severalty, to submit to measures essential to secure a full and profitable use of their property.

As a general proposition of law it is laid down that the owners of the bed and banks of a stream have the right to use the running water in common from its source to its outlet. Each one has an equal right to its reasonable use as it flows by his land. This right of each is limited by the like right of every other. But this special qualified property of the individual in the water does not seem to exclude a general paramount interest which the public retains. Consequently, while no one can justly diminish his neighbor's enjoyment by greatly vitiating the water during his own short-lived tenure of it, neither may he destroy or gravely impair the public property in it. The factory or the mill may temporarily monopolize the flow, but they do so under an implied agreement not to spoil the water for the ordinary uses of the people in general. If they pollute the stream unduly they violate their license, and may be compelled to abate the nuisance they have made. But while it is easy to lay down the principle, it is not easy to insist upon its rigid application, without danger of working injustice and of frustrating the immemorial policy of the Commonwealth. An inflexible enforcement of a rule forbidding any defilement whatever might ruin many millowners and stop half the water wheels of the State. Some diminution of purity is inevitable, and tolerable, while other contamination is unnecessary or excessive. The difficulty lies in distinguishing the legitimate from the destructive usage. A satisfactory definition is impracticable. Each case differs a little from the next. The circumstances may be utterly unlike. All will agree that some kinds of corruption may reasonably be sharply dealt with. No one, for example, pretends that he can rightfully pour human excrement and household filth into the water below his dam. Neither can he justify dumping into the river waste and refuse and garbage. On the other hand, the most exacting purist might not care to complain of the sediment washed from some bleachings or scourings, the slight taint of certain kinds of harmless chemicals, or the evanescent stain of dyes which are not unwholesome. The task is to discriminate the variety of shades of impurity which occur between these extremes.

Then there is a class of cases where it may be an open question whether it is not for the public interest to abandon a stream or sheet of water to the customary pollution of industry, so long as it does not imperil the public health. Unless this be admitted, the alternative may be to drive away thriving communities, and destroy the work of years of patient labor and active enterprise, undertaken under a presumed security of tenure. In such a dilemma, if the water is not required for drinking purposes, a considerable contamination may be suffered without inordinate inconvenience. No doubt the State cannot entirely escape responsibility, even by such a relinquishment as this. The public have a right not to be poisoned by the air they breathe any more than by the water they drink. There is a foulness which is inadmissible even in a factory stream, which may embitter the life and undermine the health of the dweller upon its banks. In such cases the State is bound to intervene peremptorily if the riparian owners remain obstinately deaf to the public protest. Generally, however, before this stage is reached, the dirt of the earlier usage has so impaired the value of the water for some subsequent taker that he insists upon an abatement of the abuse above him. Complaints frequently reached the commission that this mill or that workshop so befouled a stream that fabrics which formerly could be washed white, now came out stained and damaged. Time was, they told us, when the river water was pure enough to drink, and served perfectly well all the manufacturer's purposes. Now, the sediment it carried clogged and corroded tubes, ruined boilers, caused constant foaming in making steam, and was a perennial source of annoyance and injury in their business. And upon inspection we would find that probably the next man below our informants would echo the same complaints, attributing his troubles perhaps to the very persons who had called us in. And so on, sometimes for many miles down the stream, each successive proprietor would bewail the wretched usage which it had suffered before it reached his dam, and then proceed forthwith to give cause for more lamentation to his neighbor below. Still they cannot entirely disregard such remonstrances. Generally the moral as well as the legal obligation of abstaining from all avoidable vitiation of the water was frankly admitted, and the practice was usually deplored as inevitable rather than defended as right in itself. We are sanguine that a co-operation of water owners might be brought about, in most cases, by any board charged with the duty of mitigating the pollution of rivers, provided some practicable plan be proposed and presented to them. And we are inclined to look upon this interaction and mutual concession as likely to promise better results than a sharpening of the edge of the law. At all events we should like to see the experiment tried before resorting to harsher measures. We prefer to encourage the individual to voluntarily improve his own and his neighbor's property, and thus subserve the public interest at the same time, before we invoke the heavy hand of the General Court to coerce him.

We think it will be enough for the present to require that water for dwellings must be protected from ever avoidable taint, while water for business must not be offensive or dangerous. All wanton ill usage, such as privies over the stream, or cesspools draining into it, may well be put a stop to; and where the incidental injury characteristic of an industry is detrimental to the next user or to the public, it should be scrupulously restricted to absolutely unavoidable dimensions by the adoption of the most approved methods of remedial treatment.

But even if it should be thought expedient to impose some such restrictions as we have indicated, there is still room for much difference of opinion as to the best method of enforcing whatever regulation is adopted.

There are several ways which naturally suggest themselves. We may leave the landowners, the waterowners, and the community at large to the ordinary courts and to the common law to define and protect their various interests, or we may erect a special tribunal and prescribe by statute the scope and method of its oversight and jurisdiction, or the Legislature may pass upon each case as it arises. For reasons which we state in another place, we are inclined to recommend that the supervision of matters pertaining to water supply, sewerage, and and the pollution of waters generally, be assigned to some board which shall be clothed with powers analogous to those of the Railroad Commissioners and Harbor Commissioners, to enable it to introduce system and method in these important departments of the common welfare.

As we have extended our reasons for this provision somewhat at length in a subsequent portion of this document, we do not deem it worth while to enlarge further upon it in this place, except to point out that the function of such a board should be supplementary and not subversive of the processes, jurisdiction and rules of the common law, and the ordinary courts of justice.

After so tedious a disquisition upon the more abstract and theoretical side of the task assigned us, we recognize the obligation to hasten to present some concrete results. But, before entering upon the practical application of the general principles of sewerage science which we have very inadequately sketched, it will tend to simplify the body of this report if we can dispose of three preliminary matters at the outset. Naturally, during the long period that this question of sewerage has been impending, many projects of more or less value have been propounded, and more or less debated in the daily papers and elsewhere. There is only one of these which we deem it advisable to try to dispose of here, in order to clear the way for any really useful discussion of measures of relief. It has been suggested that the State should build a trunk sewer from Worcester to the sea, at Boston, and thus furnish the whole intervening territory with complete facilities at a blow. This scheme we consider to be entirely visionary and impracticable, for various reasons. In the first place the engineering difficulties are very great, although not absolutely insuperable. As the heights of land between Worcester and Boston run north and south, separating the valleys of the Blackstone Sudbury and Charles, several long and deep tunnels would be necessary, but it is possible to bore them. Then, as a sewer once let down cannot be got up again without pumping the sewage, it becomes necessary, in covering so great a distance to maintain a steady downward grade of a very slight and regular inclination for each mile. This aggravates excessively the difficulties of location and, by consequence, greatly stretches out the length of the route. It is is not probable that a line could be found less than fifty miles in length. But even this does not put it beyond the bounds of possibility. Then, in consequence of its meandering course, which must be governed by topographical considerations, and could not be modified to meet requirements of population, it cannot be carried from town to town like a railway, but must wind from hillside to hillside. This might, and probably would, compel towns not actually touched by the main sewer to spend more money merely to reach it than they would have to pay to treat their own sewage for themselves near at hand. Still it would be possible. All these objections are serious, but not absolutely conclusive. What we do consider, however, ought to be entirely conclusive, is the enormous cost of such a work. We do not believe that it could be completed and put in operation for less than eight millions of dollars. And when it was done we should have a piece of machinery which could do no more and no better work than can be obtained from simpler mechanism for one-eighth of the money.

A second preliminary of an explanatory character may be excused in this connection. We found, after many trials, that it was impracticable to equalize the accessibility of our trunk sewer to the various communities it was intended to serve. For example, take Medford and Malden, in the Mystic system, and compare or contrast their relations to the main sewer, as respects convenience of contact, with the position of Stoneham or Woburn. In the former, the main trunk runs its whole length through the most crowded population, and in streets where it actually supersedes the necessity of building town sewers, while in the latter only one not very convenient point of excess is furnished, and that so placed as to rather increase than diminish the length of local drainage. But, inequitable as this may seem, it was manifest, upon a full comprehension of all the surrounding circumstances, that it was one of the inherent and essential infelicities of our problem. And we were forced to come to a distinct understanding that we could not undertake to do more in any case than to furnish one suitable mouth or sink in each town, where it could empty its town sewers into the district sewer. One only could be granted as of right, more must be attributed to fortune of situation.

A third obvious but prudent warning may also find a place here. In none of our sewer plans has any provision been made for storm water. We do not provide for surface drainage. Situated as we were, it was found to involve a scale of cost which seemed to us entirely inadmissible. It may answer very well when sewage flows freely away into large bodies of water, but if it requires pumping, treating, or handling in any form, the accession of rainfall swells the discharge at times to utterly unmanageable proportions, and in any aspect is very costly and cumbrous. We think that the figures which we have to present will be sufficiently imposing without one dollar of needless expenditure. In our view the treatment of street scour as sewage is a luxury rather than a necessity of municipal life, and it seems to us that most of our towns and cities find that their necessities will probably absorb all the funds which they are quite ready to spare.

In the works on the Derwent Valley, Tasmania, Railway, there has been, an Australian paper says, an extraordinary muddle. It states that the recent floods carried away a large portion of the line, owing to the culverts being too small. Three different plans were made of one culvert, and the bridges declared dangerous.

THE BEHAVIOR OF STEEL.

From "The Engineer."

The question as to the cause of the failures of steel boiler plates, apparently with no stress upon them, or with a stress far short of their estimated ultimate strength, is at the present time creating great interest in engineering circles. It has recently been suggested that the working of steel at a blue heat, that is at a temperature below redness, say from 470 deg. to 600 deg. Fah., may have been the cause of some failures. It is a noteworthy fact that most of the plates which have up to the present time failed in this manner have been previously worked in the fire, and this to some extent bears out the theory in question, by providing the probability that at least some portion of the plate was worked at this temperature. It has long been known that there is a certain amount of danger incurred in working mild steel at blue heat, as it has been found that at these temperatures it certainly loses some of its ductility, and in the best yards and workshops steel has for a long time been worked either red hot or cold; but at the same time it has generally been considered that, if the steel successfully withstood the ordeal of working at the blue heat, it was uninjured when it became cold, and that it retained the same good qualities as if it had been worked into its place red hot. It now appears that this is not the case, but that, at least with certain qualities of steel, the ductility existing when cold is reduced by such treatment; the alteration of ductility of course depending to some extent upon the amount of working put upon the plate when at a blue heat.

A favorite explanation of the so-called mysterious cracks sometimes occurring in worked plates has been that local heating during working sets up internal stresses by the expansion and contraction of the material, in a somewhat similar manner to that in which such stresses are produced in castings. The portions locally heated become expanded when hot, and as they are bound, as it were, by the neighboring cooler portions, and not able to lengthen, and being at the same time comparatively soft, they become upset. When these portions cool down they tend to contract, but being still bound by their neighboring portions they cannot shorten, and as they are then harder and stronger than they were when hot, they become stretched, or in other words, are put in tension with an equal amount of stress to that which would be required to produce an elongation equal to that which is caused by the contraction being prevented. It is in order to relieve stresses thus produced that recourse is had to annealing, which by raising all parts to a uniform red heat allows the strained parts to stretch or compress themselves sufficiently to relieve the stresses upon them while the metal is soft. The subsequent uniform cooling then leaves all portions without strain. This argument, however, only holds good for the production of initial stresses up to the amount which would cause an elongation equal to that imposed by the contraction of the parts; that is to say, practically the stresses so produced cannot much exceed the elastic limit, and as the ultimate elongation before rupture is over 20 per cent. it is difficult to see, if the material is perfectly homogeneous, how stresses thus produced can cause the cracks they are supposed to explain. If, however, the ductility is locally altered by the treatment which produces these stresses, so that the material no longer remains homogeneous, it is evident that in the harder or less yielding portions there will be a concentration of the stress; and if any treatment could produce such a diminution of ductility as to render the plate brittle at a particular part, then these local stresses, if set up at that part, might easily produce a rupture.

The possibility of the change or alteration of the ductility of different portions of a plate is accordingly a most important consideration. It has usually been accepted that steel is practically homogeneous, and this is generally cited as being one of its most important qualities, and one in which it excels iron as a constructive material; and undoubtedly when the plates leave the hands of the makers, especially if they have been properly annealed, they possess this quality to a very high degree. But does this quality exist when the plates become part of a structure? Do none of the processes through which they pass, such as bending, hammering, punching, riveting, setting, etc., after their ductility? If they do, and a plate gets into a structure with one part harder than another, then as the stresses upon each part of the plate, when it becomes strained, depend in a large degree upon the relations existing between the deformation and the stress accompanying that deformation, the hardest or least yielding portion will bear a greater stress than the softer portions, that is, the stress will not be equally distributed, and this localization of the intensity of the stress takes place to the greatest extent in those parts which are hardest. Since rupture will commence when the local stress is equal to the ultimate strength, this unequal distribution of stress will reduce the strength of the structure below what it would have been if the stresses were uniform throughout. It is therefore extremely important that we should know whether any treatment to which steel plates can possibly be subjected during their being worked into the structure does alter their ductility, and the question as to the effect of working steel at a blue heat is one which requires thorough investigation, not only as to the kind of effect produced by such treatment, but also as to the amount of this effect. It might possibly be the case that a small amount of working at this temperature, such, for instance, as would occur in practice in closing a joint, may have so trifling an effect as to render it practically of no moment, while a larger amount of such working would be seriously objectionable. It should further be determined definitely whether the effects produced by such treatment are permanent, or whether subsequent annealing, or even local reheating to a red heat of the whole of the part affected, is sufficient to restore the ductility to its original amount. Another important point requiring solution is whether this property, which unquestionably is possessed by some mild steel, is inherent to all steel, or whether, as has been claimed by some steel makers, it is an accidental quality dependent upon some impurity in composition, or peculiarity in manufacture, and to which therefore other steels are not liable.

It is of course well known that hard steel, that is to say, steel containing a large proportion of carbon, is peculiarly sensitive to the variations of the rate of cooling down from a red heat, the quicker the rate of cooling the harder and more brittle it becomes, while the slower the rate the more ductile. It is this quality of "tempering" which makes such steel unfit for most structural purposes, and it is the comparative absence of this quality which has given mild steel such a commanding position as it now occupies as a constructive material. Yet even the mildest steel has its ductility and strength greatly modified by cooling. If made red hot and suddenly quenched in cold water 26-ton steel has its strength increased to about 36 tons, and at the same time its ultimate elongation is considerably reduced. The field of inquiry as to the ductility of steel should therefore be held to include not only the effect of working at a blue heat, but also the effect of the greater or less amount of "tempering" which can easily occur in practice in working plates that have to be fired; and this not only with the very mildest qualities of steel, but also with steel of from 30 to 32 tons per square inch.

Attention is also being given to this question in America, and we publish this week a letter on the subject from Mr. F. W. Dean, member of the American Society of Mechanical Engineers. It contains a suggestion that a probable cause of failure might be a one-sided or non-axial stress upon the material. The effect of such a stress upon a homogeneous material would be somewhat similar to that of the fairer pull upon a material of varying ductility, such as we have been considering; in each case the result is that the stress is not uniformly distributed, with the consequence that the breaking stress is reached in one part before the full strength is developed in other parts, so that the plate breaks down piecemeal. Mr. Dean states that American engineers are often struck with the small part which the elastic limit of the material plays in discussions amongst English steel manufacturers and engineers. Undoubtedly we have got into a loose way of speaking of the ultimate strength and elongation of steel as being the most important qualities it possesses, and it has sometimes appeared that in discussions on the subject by our engineers the fact has been lost sight of that the elastic limit is a limit to the useful strength of the material, and also that it by no means follows that in advancing from mild to harder steel the useful strength is increased in the same proportion as the ultimate strength, since the elastic strength does not bear an invariable ratio to the ultimate.

The experiments quoted by Mr. Dean illustrate this point. Two sets of riveted joints were made of identical dimensions, the one being made from a steel having an ultimate strength of about 26 tons per square inch, and the other from steel of about 28 tons per square inch, the ultimate elongation in each case being about 32 per cent. in a length of 10 in., but in the case of the soft steel the contraction of area was much greater than in the other, while the limit of elasticity not only bore a higher proportion to the ultimate strength, but was actually greater in the soft steel than in the other. The efficiencies of these joints, although they were identical in design, were in every case in favor of the softer steel, and their greater efficiency almost exactly counterbalanced the less original strength of the material, so that a structure of the 26-ton steel would have about the same strength as one of the 28-ton steel. Mr. Dean accounts for this by the softer steel being able to yield more when under great tension, and thus to allow the stress on the material to be more uniformly distributed, the yielding being continued longer in the case in which the elastic limit is higher than in the other.

The loose way of speaking of the ultimate strengths of materials as found by a testing machine, as though they were the actual strengths of the same materials when forming part of a structure, has no doubt arisen in part from the very common requirements of specifications as to these strengths; but it should not be overlooked that the tests which have become recognized as standards of excellence do not necessarily represent the strengths of the materials as actually applied in a structure. For instance, it is usual in specifications for cement to require samples made in a particular way to withstand certain tensile stresses, yet practically the cement in structures is never exposed to tension at all. So also with regard to steel plates, they are invariably specified to be able to withstand certain tension and elongation tests, even although they are to be used for furnaces in steam boilers, or for the compression members of a bridge, in which cases they will never be exposed to tension at all. Again, the so-called "temper test" to which steel is subjected is representative of a condition to which the material in all ordinary structures is never subjected, yet this is rightly looked upon as one of the most useful tests that can be applied to steel. The fact is, that steel, like other materials, is possessed of certain all-round qualities, and if some peculiarity in its composition or manufacture affects one of these qualities it will in general affect the others as well; and as in framing specifications it is necessary to fix some points of excellence which are capable of easy and exact determination, the ultimate strength and elongation and capacity for withstanding bending being those properties which are most readily determined, are usually those which are specified with precision. It is in this way that the ultimate strength becomes generally spoken of as the strength of the material, and the elastic strength, or useful strength, becomes lost sight of. The elastic limit, moreover, is not so easily and accurately determined as is the ultimate strength. Engineers are not even agreed as what should really be considered as the elastic limit, but there is reason to believe that in the immediate future more importance will be bestowed upon this point, as there are now trustworthy autographic indicators applied to testing machines, which, if they do not definitely record the actual elastic limit, at least record quite clearly the breaking-down point, which is not far removed from that limit. As these instruments become more generally known, it is probable that they will come into more extended use, and we shall then have specifications fixing not only the ultimate strengths, but also the elastic strengths of the material. If such a practice ever becomes general, we shall still have to remember that the useful strength is not necessarily the elastic strength, as the useful strength must still depend upon the distribution of the stresses upon the section. The uniform distribution of such stresses is principally a question of workmanship, but even with the best workmanship, it is also dependent upon the proper choice of materials. Forms which are complicated and require much manipulation to obtain accurate fitting of the parts must be made of materials which will allow the finished work to be practically homogeneous, or else, as we have shown, we cannot insure uniformity of distribution of stresses. For such forms the mildest of steel will probably be the most suitable, while there are other structures for which steel of an intermediate strength will be an admirable material, if it possesses higher elastic strength.

While the responsibility of determining what kind of steel is the most suitable for any structure must rest primarily with the engineer, and not with the steel makers, it behoves both steel makers and engineers to investigate thoroughly the whole of the physical properties of steel generally, without a knowledge of which we cannot hope to attain to that perfection for which we all strive.

THE NAVY AND ITS PROSPECTS OF REHABILITATION.

By REAR-ADMIRAL EDWARD SIMPSON, U.S.N.

ANNUAL ADDRESS AS PRESIDENT OF THE UNITED STATES NAVAL INSTITUTE.

The Proceedings of the United States Naval Institute.

Ever since I received the notification that I had been elected the President of this Institute for the ensuing year, I have had a desire to acknowledge the compliment, and to express my appreciation of the honor that you have done me in associating me with the distinguished officers who preceded me in this office. It occurred to me that the most fitting and appriate method of doing this, and at the same time of showing my interest in the Institute, would be to prepare a paper to be read at one of the meetings, or to be published in our Proceedings. The range of subjects to choose from is very wide, for as this Institute has to do with matters pertaining to the Navy, it is hard to indicate any subject known to modern progress that would not be appropriate; but I concluded to confine myself to no one of these, but rather to assume the position of an observer of what is now transpiring, to suggest what seems to me to be needful, and to consider the prospects that are held out in the way of rehabilitation of the Navy.

I am aware that in making an address I am departing from custom, but I am willing to endure the penalty that is imposed for the sake of putting before you some ideas which I could not find a more convenient method of presenting. I have been employed lately on duties relating to ships and gun foundries, which afforded me opportunities for observation and naturally encouraged thought; and it occurred to me that remarks on these subjects, and ideas resulting from the study of them, could not be altogether without profit, and might be found interesting. I accordingly devote much of my space to these two subjects, avoiding in the latter, gun foundries, a repetition of what you have read in the report of the Gun Foundry Board, but supplementing what is therein stated by some explanations, which can be familiar only to those who were members of the Board.

I was the more inclined to address you in this manner from the fact that your notice of me and my work comes at the time when, for reasons beyond my control, I am about to be retired from active service, and will be for the rest of my life only a "looker-on in Vienna," and it is for me a suitable time to sum up accounts and, as it were, to take an account of stock.

My first associations with the Navy were nearly 46 years ago. It then occupied a very creditable position, but I saw it advance to its zenith when its ships were the models for the imitation of the world, and its guns were the standard of excellence. I have seen it in its decline until its *materiel* has reach the point where it can be cited as the standard of inefficiency. Even our own daily press make it a target for its shafts of ridicule. Thanks to the Naval Academy and the abiding high tone of the service, its personnel is above reproach, and, in this day of the decadence of our ships and guns, it finds itself equipped for the trying work now before it.

This condition of preparation is the result of the training of officers at the Academy, where the door of knowledge was opened to them, and to their own individual efforts to advance in the studies inaugurated at that institution. This Institute is one of the proofs of the aspiration for advancement that felt the need of a field in which to exhibit prowess, and these efforts have been continued under a pressure that seemed to forbid any chance of encouragement. This element of success we were not favored with for many years; but let us view the outlook of to-day, let us see if we have not now a right to feel encouraged, and to believe that the tide, having reached its lowest ebb, is now on the flood on which we may rise to the position we once held.

The first and most important consideration for a navy are ships! A reference to our Navy List shows a beggarly account. What encouragement have we for the future? We have much encouragement, and I will trace with historical precision the progress that has been made slowly, indeed, but surely, in this directon.

The origin of the effort dates from June, 1881, when the Hon. William H. Hunt, Secretary of the Navy, appointed an advisory Board to consider and to report on the need of appropriate vessels for the Navy. This board, styled the first Advisory Board, decided that for all purposes of "surveying, deep-sea sounding, protection and advancement of American commerce, exploration, the protection of American life and property endangered by wars between foreign countries, and service in support of American policy in matters where foreign Governments are concerned," and for providing a "reserve of sufficient strength to maintain the effectiveness of the fleet," the United States Navy should comprise 70 unarmored cruisers.

The Board, in its report of November 7, 1881, stated that there were 32 vessels in the Navy fit for service. The required 38 vessels were classed as follows, viz.:

Two first-rate steel double-decked unarmored cruisers, having a displacement of about 5,873 tons, an average speed of 15 knots, and a battery of four 8-in. and twenty-one 6-in. guns; cost, $3,560,000.

Six first-rate steel double-decked unarmored cruisers, have a displacement of about 4,560 tons, an average sea speed of 14 knots, and a battery of four 8-in. guns and fifteen 6-in. guns; cost, $8,532,000.

Ten second-rate steel single-decked unarmored cruisers, having a displacement of about 3,043 tons, an average sea speed of 13 knots, and a battery of twelve 6 in. guns; cost, $9,300,000.

Twenty fourth-rate wooden cruisers, having a displacement of 793 tons, an average sea speed of ten knots, and a battery of one 5-in. and two 60-pounders; cost, $4,360,000.

In addition to these cruisers, it was recommended to build five steel rams of about 2,000 tons displacement, and an average sea-speed of 13 knots; cost, $2,500,000.

Five torpedo gunboats of about 450 tons displacement, and a maximum sea speed of not less than 13 knots, and one heavy-powered rifled gun; cost, $725,000.

Ten cruising torpedo boats, about 100 ft. long, having a maximum speed of not less than twenty-one knots an hour; cost, $380,000.

Ten harbor torpedo boats, about 70 ft. long, having a maximum speed of not less than 17 knots per hour; cost, $250,000.

The Board stated that "iron-clads are absolutely needed for the defence of the country in time of war," but as its orders were to recommend means of providing for the present "exigencies of the Navy," it considered this type outside of the category of vessels it was ordered to consider.

In the naval appropriation bill, approved August 5, 1882, authority was given to build one each of the first two types enumerated above, and an Advisory Board (the second) was provided to advise and assist the Secretary of the Navy in all matters relating to their construction, and "to prepare plans, drawings and specifications of vessels, their machinery and armament, recommended by the late Naval Advisory Board not authorized to be built."

The second Advisory Board was organized November 13, 1882, previous to which there had been issued from the Navy Department notice and advertisements concerning the construction of the two steel cruisers, inviting "all engineers and mechanics of established reputation, and all reputable manufacturers of vessels, steam-engines, boilers, or ordnance, engaged in the business, all officers of the Navy, especially naval constructors, steam engineers and ordnance officers, having plans, models or designs of any vessels, or of any parts thereof, of the classes authorized by the Naval Appropriation Act of Congress of August 5, 1882, to submit such plans, models and designs to the Naval Advisory Board directed to be organized by the Secretary of the Navy, under the provisions of said Act, for his advice and assistance in designing and constructing said vessels, in order that the same may be examined by said Board in accordance with the provisions of said Act."

The Board issued a circular November 25, 1882, suggesting the general features for the larger vessel authorized to be built, for the guidance of those proposing to submit plans.

The Board recommended to the Secretary of the Navy, November 21, 1882, that, in addition to the two cruisers already authorized to be built, there should also be constructed two of the ten second-rate single-decked steel unarmored cruisers recommended by the first Advisory Board; also one dispatch boat.

On January 2, 1883, the Secretary of the Navy recommended to Congress (in accordance with the advice of the Advisory Board) the construction of one steel cruiser of about 4,000 tons displacement, three steel cruisers of about 2,500 tons displacement, one dispatch boat of 1,500 tons displacement, and one cruising torpedo boat, to cost $38,000. The largest cruiser previously authorized was omitted for sufficient reasons, as she could not be built on the sum appropriated, and it was not considered judicious to build so large and expensive a vessel which is not required, and which would be very expensive to retain in commission.

On February 1, 1883, the Board submitted general features for a 4,300-ton cruiser, and on February 5, 1883, the Secretary of the Navy issued the same to ship builders and engine builders in the United States likely to make proposals for construction.

Congress in the Naval Appropriation Bill, approved March 3, 1883, provided for the construction of one cruiser of 4,500 tons displacement (Chicago), two of 3,000 tons displacement (Atlanta and Boston), and one dispatch boat of 1,500 tons displacement (Dolphin), a portion of the estimated cost being voted at that time, and the balance being provided in the temporary half-year appropriation for the Navy approved July 7, 1884.

The Secretary of the Navy, in his report of December 1, 1883, recommended, in accordance with the advice of the Advisory Board, the construction of seven additional steel vessels, viz.: One of each of the three types already under construction by the authority of Congress, and in addition to them, two heavy and two light-armed gunboats. The consideration of a bill introduced in Congress in accordance with this recommendation, produced an investigation by a Senate committee, the evidence given at which showed that, with the exception of two of the officers summoned, the Advisory Board had the confidence of the Navy.

This bill failed to pass the House of Representatives. The debate upon it in the Senate was very thorough, and showed that, in that chamber, party lines were yielding to what was felt to be a national question.

In the act making appropriation for the Navy, approved March 3, 1885, Congress authorized the construction of four additional vessels, two of not less than 3,000 nor more than 5,000 tons displacement, costing, exclusive of armament, not more than one million one hundred thousand dollars each; one heavily armed gunboat of about 1,600 tons displacement, costing, exclusive of armament, not more than five hundred and twenty thousand dollars; and one light gunboat of about 800 tons displacement, costing, exclusive of armament, not more than two hundred and seventy-five thousand dollars. This bill was passed during the last hour of an expiring Congress, and a line introduced in the House provided that the construction of these vessels should be under the direction of the Navy Department, not subject to the supervision of the Advisory Board. The general features and preliminary plans and calculations have been made for these vessels by a special Board on additional vessels, and they are now in the hands of the Bureaus, who are preparing designs on which bids can be made if proposals are issued for their construction by contract.

We thus see that, notwithstanding the apathy into which we had fallen, notwithstanding the more serious obstacle of party rivalry, whether with an Advisory Board or without an Advisory Board, the Navy can count on an addition of seven steel cruisers of modern construction, and one dispatch boat as a nucleus for the new Navy. The coming year will see four of these vessels completed, and it may be that the year following may launch the four additional vessels; and have we not a right to believe that, the inertia of rest being overcome, and the energy of motion having been communicated, the pressure of the wave of public opinion will grow in force until it will come to be a recognized necessity to make a yearly appropriation for the increase of the Navy? I think we have a right to believe it. We know that public opinion is with us, the individual legislator will agree to the necessity of the increase; it only remains for the rivalry of parties to be supressed in the face of this national question, and the signs are greatly in favor of this devoutly wished-for consummation.

It will be noticed that the Act of Congress which originated the first action in this matter was founded upon the recommendation of the first Advisory Board, and it is natural to suppose that the report of that Board will be referred to in future steps that may be taken, and if later experience does not suggest modifications, that they will form the basis for future action. We may thus conclude that the number of vessels indicated by that Board as sufficient to perform the duties of a navy in time of peace will be adhered to, and that seventy unarmored cruisers of steel will in course of time be added to the Navy list. I count the whole number of cruisers of steel, because, even at a much faster rate than that at which we propose to build, our present supply of wooden ships will have entirely disappeared before that number will be completed.

It will also be noticed that the first Advisory Board interpreting its instructions ("to provide for the present exigencies of the navy"), not to apply to armored vessels, made no recommendations as to the construction of such vessels, merely noting that "iron-clads are absolutely needed for the defence of the country in time of war." It seems to me that this is a weak position for us to continue to hold, that is, if the practical working out of the idea is to postpone the construction of armored vessels until we shall have provided ourselves with the seventy unarmored cruisers needed for current use. This is a short-sighted view to take of the matter. There is no good reason why the building of both armored and unarmored vessels should not be prosecuted at the same time; in fact, I think, it can be shown that the construction of the two classes of vessels at the same time would prove ultimately to be economical in result. But, apart from the matter of cost, does it not seem absurd to confine our preparations only to what is required in peace when it is openly recognized that the *armored* vessels are indispensable in time of war?

ARMORED VESSELS.

This view was actually taken of the subject by Senators when the bill for additional vessels was under consideration in the Senate in 1884. One Senator who declined to vote for the additional unarmored cruisers declared that he would vote fifty millions for vessels capable of contending with first-class iron-clads and of resisting modern artillery.

Taking advantage of this offer of the Senator, and with the earnest desire to give him a chance to vote his fifty millions, I addressed a letter to the Secretary of the Navy, which I place here on record as I find it embodies ideas and recommendations which I still hold to be sound. The letter was as follows:

"NAVY DEPARTMENT, WASHINGTON,
April 11, 1884.

"The Honorable W. E. CHANDLER,
Secretary of the Navy.

"SIR: Referring to the debate in the Senate on the amendments to the Naval Appropriation Bill, objection is raised by some Senators to granting additional vessels to the Navy on the ground that the cruisers asked for are not of such fighting quality as to match armored vessels of other nations, the inference being that if a bill were presented for the construction of an armored vessel it would meet with their approval.

"The first Advisory Board was fully sensible to the need of armored vessels for the Navy, but in consideration of the great need of cruisers to carry the flag abroad it recommended as the first step in rehabilitating the Navy the construction of vessels to supply this, the most pressing want of the service. Construction of armored vessels was confidently expected to follow in due order after a sufficient number of unarmored vessels should have been built to form a cruising force. It seems apparent that the building of armored vessels, and of unarmored vessels, was not proposed to be carried on simultaneously, from a disinclination to call for very large appropriations.

"For the purpose of conforming to the implied desires of Senators for armored ships, and from the fact that there is no doubt of the need of them, I respectfully recommend that the programme laid out by the first Advisory Board be so far departed from as to admit of having one armored vessel under construction constantly, even while the work of providing cruisers is in progress.

"The length of time required for such constructions is from three to five years. They are very costly, and will involve much study and careful preparation; besides, the selection of a type will be a matter requiring much deliberation.

"In relation to the last point, the selection of a type, I submit general dimensions and some particulars of two armored vessels which represent the most advanced ideas of the present day. One of these would, most probably, be the character of the vessel that would be recommended by such a body as the Advisory Board.

"H. B. M. Ship Imperieuse, not yet completed, was commenced in 1881. She is called an armored cruiser, and is intended for sea service on foreign stations where fast unarmored ships may have to be opposed, and where second-class ironclads may have to be engaged. Her dimensions are as follows:

Length	315 feet.
Beam	61
Draught	25
Displacement	7,400 tons.
I. H. Power	8,000
Speed	16 knots.

"The battery will consist of four 9.2-inch guns, each mounted in an armored barbette, and six 6-inch guns in broadside. The barbettes are arranged one forward and one aft, and the others abreast of each other at the sides amidships; the heavy guns are thus situated at twice the height from the water that they would be in a turreted vessel, and can be fired three together in any direction. The speed and armament here described does not greatly exceed that of the Chicago, but the difference in displacement of 2,900 tons admits of the following armor:

"Throughout the length occupied by the machinery and boilers (139 feet), the sides are protected by ten inches of compound armor for a depth of eight feet, the deck over this is one and a-half inch thick; bulkheads of plating eight inches thick run athwartship at the forward and after extremities of the side armor, thus forming a citadel enclosing the machinery and boilers. Forward and abaft the citadel, at the level of its lower edges, extends a protective deck three inches thick, sloping downwards to the sides, as in the Boston and Atlanta. The barbettes are seventeen feet in diameter, and are armored with eight inches of steel, which protects the machinery for turning, elevating and loading the gun, and an armored chute leading to below the armored deck makes the passage of ammunition safe and rapid. The pilot tower is protected by ten inches of armor.

"Contrasting the protection afforded by the armor above stated with the vulnerability of the Chicago, the advantage of the increased displacement of the Imperieuse becomes apparent.

"Another type of vessel that would come up for consideration is the turreted ship Riachuelo, just completed for the Brazilian Government by an English firm on the Thames. Her dimensions are as follows:

Length	305 feet.
Beam.	52
Draught	20
Displacement	5,700 tons.
I. H. Power	6,000
Speed	16 knots.

"The armament consists of four 9-inch guns in two turrets, and six 6-inch guns on the upper deck. There is an armor belt of eleven inches thickness covered by a two-inch deck, and the turrets have ten inches of armor.

"The armor protection is by no means so complete as that of the Imperieuse, nor is the arrangement of the battery so effective, but on the other hand, the speed is greater and the displacement is 1,700 tons less.

"These instances are cited to show that a Board cannot, except after the most careful study and examination, decide upon even the size and general dimensions of an armored vessel best suited for our purposes; therefore, in suggesting the form for an Act of Congress which shall the best carry out the recommendation I make in this communication, and estimating the time for completing the vessel as three years, I would propose that the authority should be given somewhat in the following form:

"For the construction of one armored vessel of not exceeding 7,500 tons displacement, one million dollars; such vessel to be constructed under the same conditions as prescribed for the construction of the steel cruisers, and its armor and armament procured, at a total cost not to exceed two millions five hundred thousand dollars.

"Very respectfully,

"E. SIMPSON, *Rear-Admiral.*"

This letter was communicated to Senators and found its way into the press. In these days of rapid development we cannot confidently count on adhering for any length of time to what we approve to-day. The development is still going on, and the advance already made may constrain us to go a step further, but in this matter of type of armored vessel I think we can claim an exception; for I find no reason to change or modify what I wrote in April, 1884, and I am inclined to think that the question is definitely settled between the casemate, barbette and turret. The first type of seagoing armored vessel naturally had the armor disposed on the broadside. The movement commenced in France, in 1858, was followed by England, and continued until their formidable fleets were equipped in this manner. In 1868 the casemate or central battery armored vessels appeared, represented in England by the Hercules and the Sultan, and in France by the Océan, the armor being limited to an armored belt at the water line, and the protection of the battery and engines by an armored casemate. In the French ship, however, in addition to the casemate for the central battery, there were introduced four barbettes, one at each of the four corners of the casemate, armored with six and a half inch plates, and mounting in each a gun of fifteen and a half tons weight. The Marengo, Suffren and Friedland quickly followed the Océan, with batteries and armor arranged in a similar manner. Since that time the construction of casemate ships has been gradually discontinued in France, and the barbette is now the adopted type, the armor consisting of a water-line protection and an armored deck covering all vital parts, while the vertical tubular passages for the passage of ammunition are strongly protected. Apart from other reasons this arrangement of armor conforms to the necessities arising from the introduction of guns of much increased caliber and weight.

In 1872 the English Admiralty built the Téméraire, in which two guns were mounted en barbette in connection with a central battery; but they did not fully adopt the type until 1882, when the Collingwood was launched. It is evident that the advantages are fully recognized now by the English authorities, for a large number of vessels of this type are now under construction. I cite here the names and displacement of those which are being rapidly pushed to completion, viz.:

Collingwood.. . . . of	9,150 tons	displacement.
Imperieuse. . . . . . . "	7,390	"
Warspite. . . . . "	7,390	"
Howe. . . . . "	9,600	"
Rodney. . . . . "	9,600	"
Camperdown. . . . . "	10,000	"
Benbow. . . . . "	10,000	"
Anson. . . . . "	10,000	"

This list is sufficient to prove that England thinks the barbette type of armored vessel has come to stay; such action implies no doubt of the efficiency of the system.

The monster ships of Italy, the Lepanto and the Italia, of 13,898 tons and 13,550 tons displacement, are of the barbette type, and that nation has now under construction three additional vessels of the same type, viz.:

	Tons displacement.
The Ruggiero di Lauria. . . . of	10,045
Francesco Morosini. . . . . "	10,045
Andrea Doria. . . . . "	10,045

Russia has ten barbette ships on her Navy list, and is continuing the construction.

In recommending, then, as I do, the barbette type of ship for our sea-going armored vessels, I think I have the experience of the world to sustain me. No more positive proof can be given of the superior advantages of the system than the practical demonstration given by the nations cited of their faith in it. There is no saving of weight of armor, but the disposition of the weight is radically different from what it is in a ship with casemated battery, and is better arranged to protect all submerged parts of the vessel, the armor deck being extended aft to the stern, thus covering all parts of the steering apparatus, while forward it gives most valuable support to the ram. The only question that could arise in selecting a type would be between the barbette and the turret system, but for sea-going purposes the increased height in the disposition of the battery given by the barbette, as compared with the position of the battery in a turret ship, must be recognized as an advantage hardly to be equalled by any others that the friends of the turret could advance for their type. And even for coast defence, or for harbor defence, the barbette system presents so many advantages that it seems to be possible for it to be substituted for nearly all purposes where the closed turret is now used. This probability increases with the increase of calibre of the guns, for it must be remembered that with the turret system the port is very near the deck, and the blast from the discharge of a 100-ton gun is something tremendous. There is a dearth of experiments on the effect of blast at the muzzle of a gun. They are much needed to assist in the investigation of this very point.

Having stated my conviction that there should be no delay in commencing the construction of armored vessels, and having given you the reasons for my preference for a particular type of vessel, and believing that type is sufficiently established by the experience of the world to justify us in accepting it as a standard, I submit to you now a few of the general features of such a vessel as I would advise. It is not exclusively my own design; it is evolved from the deliberations of a body of earnest men who considered the question carefully.

I premise by saying that we are restricted as to the displacement of our armored vessels. It is impossible for the United States to utilize such a vessel as is ranked as first class by other nations; we have not a sufficient depth of water on our bars. It is a question of draught of water. Again, the dimensions of the vessel must be governed by the size of our dry docks; that building at Mare Island is the only one that would admit a first-class ironclad, while those at Boston and Norfolk limit the extreme breadth to about 58 ft. Here is an absolute limit set on two dimensions, and, confining the length to near 300 ft., in order to ensure handiness, it will be found that, combining these with the two other governing qualities of large margin of stability and space for well-protected machinery, the maximum displacement will be fixed at about 7,000 tons.

The principal dimensions of the hull would be:

Length.	320 feet
Breadth.	58 "
Mean load draught.	23 "
Load displacement.	7,300 tons
Maximum speed in smooth water. .	16 knots

The battery should consist of four 10 inch B. L. R. guns, each mounted *en barbette* within a fixed turret nineteen feet in diameter, one located on each side amidships, and the other two on the middle line of the upper deck, one forward and one aft; the guns to be protected from machine fire by revolving hoods of 4-in. steel, the axes of the guns of the side turrets to be twenty-one and a half feet, and those of the middle-line turrets twenty-three feet above the load-water line.

Four 6-in. B. L. R. guns should be mounted on the upper deck protected by circular revolving 4-in. steel shields.

A suitable secondary battery should be carried, consisting of Hotchkiss single-shot guns of 57 and 47 millimeters, and revolving cannon of 37 millimeters, and Gatling guns.

The allowance of ammunition should be 100 rounds for each 10-in. and each 6-in. gun, 1,500 rounds for each large Hotchkiss gun, and 800 rounds for each 37 mm. gun.

Four hundred and forty-five tons should be reserved for the weight of ordnance.

There should be separate magazines and shell rooms for each turret.

The hull should be built of mild steel with brass stem, stern post and rudder should be cased with wood to the height of the main deck, and sheathed with copper.

The armor protection should consist of a belt eight feet in depth, three and a-half feet above and four and a-half feet below the load line, extending throughout the length of 150 feet occupied by the machinery and boilers and central magazines, the ends being enclosed by athwartship bulkheads nine inches thick, the thickness of the side armor being ten inches from the top to one foot below the water line, and tapering thence to five inches at the lower edge of the belt.

The armor on the barbette turrets should be seven feet deep and eight inches thick, on the pilot tower five feet deep and six inches thick, on the hoods to barbette guns four inches thick, and on the ammunition tubes to turrets four and a-half inches thick.

At the level of the top of the armor belt and throughout its extent, there will be an armored deck two inches thick, and before and abaft the armor belt the armor deck is continued to the extremities at the level of the lower edge of the armor belt, or four and a half feet below the load-water line amidships, sloping at the sides, and at the bow to strengthen the ram.

The ship will have such sail power as can be carried on two steel lower masts, to be fitted to carry circular tops for machine guns and extra gaffs or derricks for hoisting torpedo boats.

Provision should be made for carrying and launching two sixty-foot torpedo boats in addition to the usual allowance of boats, and the vessel should be designed with refence to being ultimately fitted with above-water launching gear, in four places, for an automatic fish torpedo.

The coal supply at load draught should be 500 hundred tons, with bunker capacity for 800 tons; and arrangements should be made to stow provisions for 400 men for 90 days, and other stores for the usual periods.

The engines and boilers should be capable of developing 7,500 I. H. P. in the aggregate, during a six-hour full power trial, the fuel to be the best semi-bituminous coal.

The fire rooms should be made air-tight, and fitted with centrifugal fans of sufficient capacity to maintain therein a pressure above the atmosphere equivalent to a column on one and a half inches of water.

There should be twin screws actuated by two sets of three cylinder direct-acting vertical compound engines, the two engines complete being contained in water-tight compartments, separated by a longitudinal middle line bulkhead.

It is proposed that the steam should be supplied by twelve three-furnace cylindrical boilers, having an aggregate grate surface of 900 square feet.

The total weight of the machinery, boilers and appurtenances, including water in boilers and condensers, all fittings, tools, stores, spare machinery, ready for sea, should not exceed 1,400 tons.

This is the vessel recommended to the Secretary of the Navy by the Advisory Board, "a part of which I was."

I believe this ship to be a sound basis to work on. Controlled as we are by nature in the displacement to which we can attain, and satisfied as I am that we have reached the type of vessel that will remain permanent, I see no reason why we should delay commencing the construction of our sea-going armored fleet. This fleet should consist of ten vessels, forming the outer line of defence of the coast in war, always available for operating abroad either in peace or war, and affording a school of practice and instruction in peace to prepare us for war.

COAST DEFENCE VESSELS.

But in addition to sea-going armored vessels, we are sadly deficient in vessels for coast or harbor defence. We have sixteen ports on the Atlantic coast to guard, besides San Francisco and other points on the Pacific coast. For this purpose we require a fleet of heavily-armed and armored turreted, or barbette vessels, to cover the coast as a second line of defence, and to concentrate at any time at the point attacked. These vessels should be of moderate speed, but as near invulnerabe as possible, and armed with batteries that should be irresistible. Two classes of this type would be needed in order to provide for operations in shallow as well as in deep water. With the experience of others, and our own, we could easily determine upon the general features of suitable vessels for this service. The distinct duty for which these vessels would be designed would be to engage armored vessels; consequently all other considerations would have to yield to protection of the hull and the power of the guns. The heavier class should carry guns of 100 tons weight, and the lighter class of guns, say, 50 tons weight, and I consider that 25 of such vessels are needed to complete the second line of defence. The lightly armored and indifferently armed monitors that we now have on the Navy list can be utilized in the third line of defence until more suitable vessels can be provided, and in concert with systems of torpedoes, will serve as the defence for harbors and mouths of rivers.

I think that it is very desirable that the construction of the coast defence vessels should go on at the same time with that of the unarmored and armored cruisers. There is no sufficient reason for delaying in either case. As all will be ultimately needed, it is poor policy to delay the work on one until it is completed on others. The navy yards are idle; no more suitable work can be found for them than the construction of armored vessels. The shipbuilding interests of the country are at a standstill; no more appropriate or congenial work can they find to fill up the interval of stagnation than the building of unarmored cruisers. The work would give occupation to tens of thousands of mechanics and laborers, and new industries would be started in the country.

In this connection it is proper to put prominently to the fore the absolute necessity of completing at once the four double-turreted monitors, which lie in an unfinished state at the yards of the contractors. These vessels have been assailed for one reason or another, and the effort has been made to impair confidence in them. I know not how far these efforts have influenced the mind of the Navy, but in order to clear up any doubts that may exist I will quote from a report made by the Advisory Board, in October, 1883, in which the Board states its reasons for recommending the immediate completion of the ships.

The Board says: "It is our opinion that it would be wise and expedient to finish the vessels at once, and for the following reasons, viz.:

1st. The hulls as they are at present are of excellent workmanship, fully up to the present standard condition of iron-ship construction, whilst the flotation of the Puritan and the behavior of the Miantonomoh at sea confirm the correctness of the calculations of the designs.

"2d. It is easily possible to complete the vessels by taking advantage of the recent developments in armor, guns and machinery, without making any radical changes in the designs, so that their speed, endurance, battery power, protection, and sea-going qualities shall be fully equal to those of any foreign iron-clad of similar dimensions designed previous to 1879.

"3d. The vessels may be finished so as to develop all the abovementioned advantages without making their total cost when completed in any way exorbitant compared with the results obtained; again, the interests of our sea-coast defence require a force at least equal to that which would be represented by these vessels.

"We take the liberty of calling your attention to a certain erroneous impression which now exists with regard to these vessels. In one of the official reports on these hulls a doubt was thrown upon the correctness of the calculations of the Puritan. This doubt has spread in the public mind until it includes all the ships. The actual flotation of the Puritan and the Miantonomah proves beyond question, not only the reliability of the calculations, but also that the hulls of these vessels are lighter in proportion to the total displacement than those of any ironclad low freeboard hulls afloat, with but two exceptions.

"It has been the unfortunate custom, in arguments as to the value of the results to be obtained, to compare them with such foreign ships as the Inflexible and Duilio, to the evident disadvantage of the monitors, no account whatever being taken of the fact that these vessels are double the size of the monitors. If these hulls be compared with foreign ones of similar dimensions no such disparity will appear."

Here I close the extract from the report of the Advisory Board. This statement should set at rest all doubts as to the efficiency of the vessels, and the work should be resumed on them with view to their completion at the earliest practicable moment. It is well to add that five other Boards have made similar reports recommending the completion of the vessels.

These vessels, with the exception of the Monadnock, have their machinery in place, and are finished as to their hulls, except the interior fittings, side armor and turrets.

The estimated cost to complete them is as follows:

Puritan	$1,141,481
Terror	786,267
Amphitrite	797,563
Monadnock	1,074,069
Total to complete	$3,798,380

TRAINING VESSELS.

Before dismissing the subject of ships, I should mention a serious want of the Navy in the lack of suitable sailing vessels for training boys and for the exercise of naval cadets in practical seamanship. The system for training boys for the Navy is now established on a basis that seems to work satifactorily, but, singular to say, the article that is of the very first consequence is that in which we are the most deficient. The few remaining sailing vessels of the Navy are devoted to this duty, but they are so old and are so constantly in need of repair that in a year or two they also will be withdrawn from service. At best, however, they are inefficient vessels, particularly in consequence of the size of their spars and weight of sails; they are too large and heavy to be handled by boys. This objection also obtains in the case of the vessels assigned to the naval cadets. The Naval Academy and the Training School should both be provided with ships of the Dale class, composite built, full-rigged. Six of these vessels should at once be provided. They would be launched in a few months at a cost of about $175,000 for each.

Amid the pressure of advanced ideas and the earnest efforts of progress, the basis of a seaman's education should not be forgotten. Seamanship must not be neglected, and it is at an early age that the knowledge must be acquired. All old officers will agree that they learned their seamanship during their midshipman's career. Learned while young, the knowledge will remain for life and will form the source from which we can draw to our aid in all other branches. There is nothing like it for developing the power of resources and the invention of expedients. A seaman is never helpless. If one means fails he will try another. He can work without tools. The sailing of a ship, the handling of spars, the trimming of sails, the hoisting of weights, the stowing of a hold, all give him an instinctive knowledge of practical science, and above all, a seaman trained to a sailing ship acquires a degree of personal confidence which can come from no other source. We may say that we have now no sailing vessels in general service, hence the necessity of more earnest training in this branch before an officer or man is launched into the regular service. A ship combining sail and steam is not a suitable vessel for training purposes for officers or men. Sailing ships, pure and simple, must be applied to this use, or the education will be sadly deficient.

GUNS AND GUN FOUNDRIES.

The gun as the thing of next importance merits attention. How do we stand in respect to this important element, which stamps the character of the ship, and to the efficient working and handling which all the designs of the constructor and engineer must be accommodated and made subservient?

We are fortunate in one very important point in the matter of the gun wherein our delay in commencing work has proved of advantage to us. We have adopted a type of gun which all agree is the best. There is no difference of opinion among us. We have received the Vavasseur method of construction as the one superior to all others, and we are confirmed in our judgment by that of other nations who, having embarked in other systems, have now abandoned them and accepted that of Mr. Vavasseur. Woolwich has abandoned wrought-iron, and the efforts of the steel manufacturers of England are now put to a severe test to supply steel in masses of sufficient size to answer the demand, and what is now called the Woolwich gun is the Vavasseur gun, so determined by the Ordnance Select Committee. The Krupp construction is also modified so as to include the Vavasseur long jacket; and the French, though yet somewhat divided between the plans of General Dard of the Marine Artillery, and Colonel de Bange, on whose ideas the army guns are constructed, are approaching the Vavasseur standard. The guns that we see slowly progressing at the Washington navy-yard are Vavasseur guns pure and simple.

You all know how much the matter of the gun has occupied my thoughts, and, though, for reasons beyond my control, I have not been privileged to direct in any way this arm of the service, you can readily understand what a gratification I enjoy when I see the ideas that I advanced many years ago being carried out and executed by the present accomplished Chief of the Bureau of Naval Ordnance, an officer well fitted to carry forward the work, and with time before him on the active list to perfect it. I sympathise with him in the extra work imposed upon him in having to invent expedients for manufacture instead of having at his disposal a suitable plant. I will review the steps that have been taken to supply this deficiency.

By Act of Congress, approved March 3, 1883, there was established a mixed Board of Army and Navy officers called the Gun Foundry Board, whose duty it was to take into consideration and to report on the best means of making ourselves independent in the matter of manufacturing modern cannon. It seemed to be a foregone conclusion with the framers of the bill, that the gun to be manufactured was to be of steel, and that this new manufacture could not be performed by the means at the disposal of the country, which had, up to the time of the Act, manufactured guns only of cast-iron. The Board was not called upon to deal with the matter of gun construction; its province was to recommend suitable sites, tools and all apparatus for the manufacture of guns, and to submit the approximate cost. In the early part of its labors the Board could derive no assistance whatever from our own steel manufacturers. They had not taken the matter into consideration, they possessed no tools calculated to do the work required, none such were made in the country, and the capacity of their furnaces and forging apparatus was insufficient to cast the masses or to forge the ingots required. The information required was gained abroad, and I do not propose to repeat to you the contents of the report made on the subject to Congress. The report has been widely circulated in the Navy, and it attracted much attention from the steel manufacturers at home—so much so as to remove the wall of partition that seemed to exist between them and the Board when they were first approached, and to cause them to come forward and assist the Board in the preparation of its supplementary report, which was called for in order to present in detail a method by which the recommendations of the Board in the original report could be made a practical thing. The plan proposed by the Board for putting in execution its recommendations is the basis devised by the business minds of manufacturers on which they will be prepared to offer bids if proposals are issued by the Government. It is on the successful working out of this business arrangement that our hopes of speedy rearmament depend. I will point out the difficulties that encompass the subject, and you then can judge what encouragement we have to hope for a supply of modern guns.

You are aware that the Gun Foundry Board decided that there should be no Government foundry. The share of the work of the Government was limited to that comprised in gun factories, one for the Army and one for the Navy, in which is done the finished-boring and turning, rifling, fitting breech apparatus, and assembling parts; all work of foundry proper, including casting, forging, rough-boring and turning and tempering was relegated to the private industries of the country. There is no question of the inability of any foundry in the United States to perform the work required. Mr. Sellers, of the Midvale Works, near Philadelphia, has succeeded in supplying some tubes for 6-inch guns, and the Cambria Works, at Johnstown, Pa., have undertaken to make some hoops, but this is all that can be achieved by their limited equipment. The limitation in the case of the Cambria Works applies only to its forging, boring and turning apparatus. It possesses furnace capacity for casting the largest ingots required for cannon. A manufacturer undertaking the work of supplying the material for all classes of guns must erect a suitable plant.

The cost of the plant is stated as follows, taken from the report of the Gun Foundry Board:

Casting	$250,000
Forging (hydraulic press)	150,000
Rough-boring and turning	210,000
Tempering	50,000
	660,000
Additional cost if liquid compression be adopted	175,000
	$835,000

The cost is based upon prices abroad; in round numbers the manufacturer must expect to invest one million dollars in a plant. He cannot expect to do this unless he is satisfied that it can be kept in operation for a certain time sufficient to remunerate him.

It is also necessary that the time during which the plant would be employed should be continuous, and this must be assured, for the purpose of avoiding the uncertainty attending annual appropriations which depend upon the will of each Congress to be continued or withheld. It thus becomes necessary that a lump sum should be secured for this purpose, which would stand for a guarantee for the execution of such contract as might be made. The question, then, was what sum of money was necessary to appropriate in order to secure the contractors, and assure a supply of ordnance for the Government.

The necessary outlay being so large, and the Government desiring only to treat with the most responsible parties, it seemed reasonable to suppose that those embarking in the work would be very few in number, probably but two establishments would take it up, one for the Army and one for the Navy. On this supposition the calculation was made on a unit of works, that is, to find the amount sufficient to induce one establishment to go into the business.

An output of 2,000 tons of forgings per year was taken as a basis for production. It was estimated that the average price of the steel would be twenty-five cents per pound, some more, some less; this gave $559 as the cost per ton of 2,240 pounds. At this price the cost of the yearly production of 2,000 tons would be $1,118,000. Allow, as a fair profit to the business, 15 per cent. of this amount, and we will have for yearly profit the sum of $167,700; and continuing this for six years and a half, the profits will amount to $1,090,050, a little more than the amount of the original outlay. The lump sum required to be appropriated for this purpose would be six and a half times the amount of the cost of the yearly production, or $7,367,000. This agrees with the report of the Gun Foundry Board, in which you will notice that the sum mentioned as necessary to be appropriated is $15,000,000, one-half for the Army, one-half for the Navy, that is $7,500,000 for each arm of the service, such amount being sufficient to secure the supply of material, at the same time assuring the contractor of a fair remuneration. This explains the figures given in the report of the Board.

I call your attention now to the wording of the proposals recommended to be issued for this work. "Said proposals shall divide the steel required into two lots. Each lot shall include all the parts for one-half of the number of guns for each caliber; each bid must include all of a lot or lots."

You see that, though the calculations for cost were made on the basis of a unit of works, there is nothing in the proposal favoring a monopoly in the work. Several manufacturers may bid, and the work be thus divided; this would result only in a more remote remuneration for their outlay. But the Board takes the precaution to require that in bidding for a lot or lots the contractor shall undertake to supply all the parts of the lot for which he bids; this ensures that his works shall be thoroughly equipped for the work he takes in hand. It would be a want of foresight to arrange the lots so that a few small establishments could bid for all the small parts, leaving only the heavy work to be done by those establishments who are willing to bear the expense of erecting a large plant. It is all important to the country as a means of National defence that these large plants should be erected, and all means should be taken by the Government to encourage the work; thus, by requiring all parts of the gun material to be included in a lot, an advantage is given to those establishments which propose to make their plants complete.

Supposing contracts to be made for the material, you may accept the period of delivery, stated in the Board's recommendations relative to proposals, as deserving of all confidence. It required that "Each bidder shall agree to deliver yearly a specified quantity of each caliber, the time of delivery of the smaller calibers to commence at the expiration of not more than eighteen months, and that of the largest calibers at the expiration of not more than three years from the date of the acceptance of the contract." This estimate is determined by positive information on the time necessary to duplicate the best tools now in use at the largest foundries abroad. The supply of the plants is an affair that would be entirely in the hands of the manufacturers themselves, who would naturally consult their own interests in equipping their establishments; it would be for them to choose between adopting tools of approved utility purchased abroad or encouraging home manufacture and risking failure by undertaking the work with the first productions of a new industry. There can be little doubt that, being bound by contract as to the time of delivery of the production of their works, they would wish to commence operations with tools of well-known capacity; the home manufacture would naturally follow, and would, no doubt, improve on the standard, but it would be a great risk at the inception of the manufacture to work with untried implements, The time for delivery of the productions of the foundries is predicated upon the supposition that the first tools used will be bought abroad, and upon the known capacity of such tools to turn out a certain amount of work in a given time. On any other basis the time of delivery would have to be indefinitely extended, in fact there would be no data on which to make a calculation. So much for the foundry work.

It is manifest that the delivery of the the tempered material for guns, rough-bored and turned, is of no avail unless the gun factories are prepared to take the parts as they arrive, and to smooth-finish and assemble them. These indispensable establishments must be organized while the material is in course of manufacture.

The cost of a plant for a gun factory is given as follows by the Gun Foundry Board:

Guns up to 6-inch caliber............	$50,000
" from 6-inch to 12-inch caliber...	150,000
" " 12-inch to 14-inch caliber..	350,000
Buildings and shrinking pit..........	350,000
	$900,000

"Three years will be required to complete the tools, construct the shops, and establish the plant."

This period is intended to represent the time necessary to complete the factory, equipped for the fabrication of cannon of all calibers up to the largest available for warfare. The building and the tools required for the smaller calibers, including those for 8-inch guns, could be prepared in less time. The building, for example, could be erected in one year, and the smaller tools could be delivered and put in place in a year and a half, which, you will notice, is precisely the period of time required for the commencement of the delivery of the material for the smaller guns. Thus the time for the delivery of the material and the time when the factory would be ready to receive it synchronize, and if the authority to erect the factory be given at the same time as the contract for the manufacture of material the work will go on harmoniously from the commencement. It is evident that the two operations must be regarded as necessary parts of one transaction; one is of no practical use without the other. In the case of the gun factory, as in the case of the foundry, I have to state that the cost of tools is predicated on prices obtained abroad, and the time of their delivery on what is known as the period required for duplicating those in use in England, France and Russia.

I hope that the practical thoroughness of the report of the Gun Foundry Board is appreciated by the services. I make this remark before a naval meeting in order to point to our indebtedness to our brothers of the Army, with whom we share the credit of the work.

We thus see that, if during the approaching session of Congress, there should be enacted all the legislation necessary to equip the two arms of the service with modern ordnance, and if the steel manufacturers should respond to the proposals of the Government, it would not be before the early part of 1888 that we would be able to commence the fabrication of the smaller guns at the factories, and not until a year and a half after that that we would be ready to take in hand the guns of the largest caliber. It is very evident that, in comparing our chances of speedy acquirements of ships and guns, the ships are the more readily attainable. For their construction we have ship-yards whose plants can be readily supplemented with the additional tools that will be required; but for the fabrication of cannon we have yet to commence the erection of plants and to inaugurate the manufacture of the material. We have the satisfaction of knowing that, since the presentation to Congress of the report of the Gun Foundry Board, a committee has been appointed in both houses to take into consideration the capacity of the foundries in the United States to provide steel for ships and guns, as well as the capacity of our ship-yards to construct modern ships of war. This action on the part of Congress is a step in the desired direction, and if time be found during the session for the deliberate treatment of National subjects, we may expect that some definite method for advancement may be matured.

ARMOR.

Another sign of encouragement is to be found in the establishment of the "Fortifications Board," on which the Navy is well represented by two members of this Institute. There can be no doubt that this Board will recommend that one line of the coast defence shall consist of armored turreted or barbette vessels, the construction of which would call for a large supply of armor plates. Here we see another powerful reason for the establishment of foundry plants.

If it shall be decided to commence the construction of armored vessels, and to face forts with armored plates, it will be necessary for the Government to make a definite selection between the steel plate and the plate of compound armor. The compound armor, again, is not all of one patent. The Cammel plate, consisting of a previously prepared iron plate on which the steel facing is cast, is all prepared in the rolling mill; the iron plate is rolled to dimensions, and, after the steel facing is placed, it is finished by passing through the rolls. With the Brown compound armor plate, however, the iron plate is prepared as before, but the steel plate for facing is also prepared separately, and this is forged under a hammer. The steel plate being then placed on the iron plate, separated from it by distance pieces, melted steel is poured into the space between the plates, thus welding the one to the other; it is finished by being pressed through the rolls. In this case we find a necessity for the heavy forging hammer or press. The steel plate, as manufactured by Mr. Schneider, at Le Creuzot, is worked entirely under the hammer, is tempered and subjected to other treatment. My own judgment favors the steel plate. I think it more in the course of advanced ideas, and I am content with the results it has achieved in experiments; and the more experience we have in the manufacture, the more will we approach perfection in results. If the steel plate be adopted by the Government, we see how indispensable it is for us to be provided with large forging facilities, whether with the hammer or forging press.

I am aware that at Terre Noire, in

France, it is claimed that a good steel armor plate can be cast which needs no forging, and I am under the impression that the same idea obtains at one of our own large steel establishments, but I have no confidence in such material, and I think that the first shot from a modern gun would dispel the illusion of those who entertain the idea. I accept as a fact that for the manufacture of steel armor plates there is required a heavy forging plant, and if we possess such facilities for forging our ingots for cannon we have secured apparatus that will be equally serviceable for treating armor plates.

An approximate calculation will give an idea of the amount of material that would be required for the purpose of the Navy. Supposing that the United States should undertake the rapid construction of an effective ironclad fleet, including armored cruisers and vessels for coast defence, the largest probable rate of construction would not exceed the completion of one armored vessel of 7,000 tons displacement, and two of 5,000 tons each year. This would require a total annual expenditure of seven and a quarter millions of dollars, and an annual supply of armor of about 3,800 tons, including their armor for protective decks and protecting shields for light secondary batteries.

During the first year after the construction is commenced, not more than half this amount of money above estimated would be expended, nor half the armor required. This approximate estimate is made supposing that the amount of armor now carried by modern vessels will continue to be used. In addition to the above supply of armor for new ships, the completion of the double-turreted monitors now on hand would require an immediate supply of 3,000 tons.

Nor must we forget the amount of material that would be required to *arm* the ships that I have proposed. There will be required for the batteries of the seventy unarmored cruisers, the ten armored cruisers, and the twenty-five coast defence vessels about 7,000 tons of *guns*, which we may roughly estimate at about 10,000 tons of forgings.

I give these estimates to illustrate the high figure to which the wants of the Navy swell. It is well that we familiarize ourselves with the idea of large masses of material and large expenditures of money; the rehabilitation of the Navy is a work of magnitude, and Congress and the people must be approached without disguise. The steel manufacturers may also recognize their opportunity, and find that their interests lie in supporting our efforts.

TORPEDOES.

Everything relating to torpedoes is legitimate work for the Navy, and merits the close attention of this Institute. Although the stationary mine for the defence of the coast is relegated to the Army, yet it is a weapon which we may, either at home or abroad, be called upon to manipulate, and our instruction in it is very thorough at the torpedo station at Newport; but the movable torpedo is the one that more especially demands study and development from us. In seeking for indications of advancement in this field, the difficulties that surround it are impressed upon us by the paucity of the results. The essential requirements are perfect control of direction both vertically and laterally. The Whitehead torpedo is the only one that possesses these attributes sufficiently pronounced to justify its being issued as a war implement. The control of the movements of the torpedo is effected by means of two rudders, the one vertical, controlling the horizontal deviation, which must be permanently set at such an angle as experiments with each torpedo show is necessary to make it go straight; the other horizontal, regulating the immersion, which is actuated by a piston under air-pressure governed by the hydrostatic pressure of the surrounding water. The principle on which the latter result is achieved is recognized, but the device itself is only known to the experts of those nations who have paid the price demanded for the information, and its nice adjustment is the result of multitudes of experiments, and the expenditure of large sums of money. The results seem to be very satisfactory, but the control over the lateral deviation of the Whitehead torpedo does not meet all the circumstances of service. I believe I am correct in stating that no confidence can be placed in the operation of it when discharged from the broadside of a vessel moving through the water. When fired ahead or astern the direction is sustained as originated, but its course is very erratic when projected under other conditions.

In this respect the torpedo of Captain Howell, of the U. S. Navy, is much the better equipped, for the power being stored in a fly-wheel revolving in a longitudinal vertical plane, its gyroscopic tendency makes it impossible for the torpedo to deviate from its original course in a horizontal plane. His device for regulating immersion is not yet sufficiently perfected to ensure the required action with certainty. This can only be done by repeated experiments, which must extend over considerable time, and involve the expenditure of much money. Thus far the Government has expended but a few hundred dollars to assist the development of this torpedo, but as its good points are the more appreciated, the chance increases of securing liberal aid for experiments. We have good expert opinion for the belief that the Howell torpedo is the successful rival of the Whitehead.

But it is important to note the effects that have been produced by the introduction of the Whitehead torpedo. It has introduced an element into the calculations of war that interfere materially with the conclusions that had been reached on the equipment of ships.

The introduction of the weapon involved that of means to utilize it, and some ships were fitted with tubes from which it could be projected. The next step was the construction of very fast torpedo boats, assigned to ships capable of stowing them, which were expected to be launched at sea to assist in a naval action. The general adoption of this idea has led to the construction of larger vessels having increased speed, which, apart from the destruction they are expected to work by their torpedo attack on large vessels, are designed to act as torpedo boat catchers, and, in addition to their torpedo battery, are fitted for this purpose with a formidable supply of rapid-firing single-shot Hotchkiss and revolving cannon capable of perforating all parts of a torpedo boat.

The French style this type of vessel a "dispatch torpedo boat," and they are represented by the first one of the class called La Bombe, which was launched in August last at Havre. Eight vessels similar to La Bombe are now included in the official list. These vessels measure about 196 feet in length, with a draught of water of about six feet, on a displacement of 360 tons. They are built entirely of steel, and care has been taken to make the hull as light as possible, and at the same time strong enough for the navigation of the high seas. They develop about 1,800 horse-power of engines, attaining a speed of nearly 18 knots. They have three masts, and are provided with the latest improvements for handling torpedoes, and with apparatus for electric lighting, etc. Hotchkiss single-shot and revolving cannon form the gun battery. The tubes for the Whitehead torpedo are above water on each bow, parallel with the keel.

The British Admiralty have prepared designs for this new class of vessels called "torpedo gunboat," and in October last issued proposals for their construction to leading shipbuilders in England. These vessels measure about 200 feet in length, while their displacement with a mean draught of about 8 feet will be 450 tons. They are to be built throughout of steel, the decks covered with wood planking. They will have four torpedo-launching tubes, one forward, one aft, and one on each broadside. Their gun armament will include a breech-loading 4-in. gun, and four three-pounder (47 millimeter) rapid-firing guns in addition to the machine-gun armament which it is now usual to supply to torpedo boats. They will be provided with twin screw engines of a total horse-power of about 2,700, and the speed expected is from 18½ to 19½ knots. They will have a protective deck of about three-quarters of an inch in thickness, with a protection of coal of about three feet thick around the boilers and machinery.

We see from this what are the constituents of a modern fleet. The armored ships form the line of battle-ships; these are attended by tenders and dispatch boats and by the torpedo boats, which they launch before going into action, and to these are added the torpedo boat catchers, whose province it is to destroy the torpedo boats of the enemy with their guns, as well as to operate as occasion may serve with torpedoes against their battle ships. All of this formid able array of boats and small vessels is now considered necessary for the protection of the battle ships against the spar and Whitehead torpedoes.

Admiral Hobart Pacha, who commanded the Turkish fleet during the Turco-Russian war, gives his experience on this subject, and he considers that the power of the torpedo as a weapon of offence, as well as of defence, is enormously exaggerated. He does not deny the deadly effect of the weapon itself, but he rates the difficulties of successfully applying it very high, and with vessels at anchor he shows most effectively how the attack can be guarded against even with improvised means at the disposal of any well-equipped vessel of war. He anchored his ships in groups of four. These were surrounded by the boats of the vessels, twenty-four in number, which were anchored in a circle, and connected together by a wire rope which is buoyed half way between the boats. The boats are estimated at nine yards in length, the twenty-four spaces between the boats are fifty-four yards each, the radius of the circle described by the boats is five hundred and fifty yards, which keeps them four hundred yards from the ships. The wire rope is suposed to be immersed two feet in the water.

The object of the rope is to catch the screw of any attacking torpedo boat. The Admiral states that "it has been proved that common rope, used for want of anything better, has effectually checked the career and capsized an attacking torpedo boat in her attempt to destroy a Turkish ship in the Black Sea during the last war; and I know that most satisfactory experiments with the wire rope have been made elsewhere. The result of these experiments was that a torpedo boat, steaming nineteen miles an hour, has capsized while dashing full speed on to an imaginary enemy's ship." An instance is also cited in actual practice where a most gallant and dashing attack made with a spar torpedo was frustrated by this system of guard.

In Admiral Hobart's article he incidentally contributes most important testimony to the ease with which the Whitehead torpedo can be made to deviate laterally from its course. He says: "One of these torpedoes struck the chain of the flag ship and went on shore unexploded; another struck on the armored belt of a corvette and exploded, but, the blow *being at an angle*, it did no material injury." If we apply this evidence to the comparative directive power of the Whitehead and the Howell torpedo before referred to, we will see that in the two cases cited, where for want of directive power the Whitehead torpedo failed to accomplish any result, the Howell torpedo, possessing this property to an eminent degree, would have resisted the effort to deflect it, and would have achieved its object. This strikes me as very conclusive that it is a necessary requisite for an automatic movable torpedo to have inherent in it a positive directive force, so as to resist efforts calculated to cause deviation. The want of this is a defect which we find in the Whitehead, but we have it in the Howell torpedo as its most essential characteristic. I take much interest in the experiments with the Howell torpedo, and I hope the Government will carry them on on a liberal scale. I have faith in its success.

What has been stated is sufficient to show that there are two sides to the torpedo question, or rather, that the power of attack with the weapon is so much neutralised by means available for defence as to deprive it of the prestige it had acquired before means of defence were inaugurated. In shallow waters or in harbors where stationary mines can be planted or floated at convenient depth of water, they are a sure means of destruction, but with net protection, cordons of boats, secondary batteries and a bright lookout the evidence goes to show that to the present time the effect in offence has been very trifling in result. The great expense, however, of the present battle ships makes it necessary to guard against all chances of service, and thus we see that the nations having the most at stake in this matter consider it necessary to protect their fleets with supplementary squadrons of torpedo boats and again with torpedo-boat catchers. Thus far the matter rests much in the realm of theory; it remains for the realities of war to solve many of the questions which are now matters of opinion and discussion.

It will be noticed that in stating the constituents of a modern fleet, no mention is made of the ram. This class of vessel, built with sole purpose of operating the ram unsupported by other weapons, was considered some years ago as a suitable vessel to accompany the battleships and to take advantage of the melée to ram the enemy, but advancement in the development of this idea has ceased since the adoption of the torpedo boat. At present we find in the English Navy vessels either turret rams, as the Conqueror and Hero, carrying heavy guns in a single turret, or torpedo rams, as the Polyphemus, with complete facilities for ejecting the torpedoes, and armed with rapid-firing cannon and machine guns for defensive purposes, but no vessel intended to operate solely with the ram. It seems to be conceded that all the useful purposes of a ram can be performed by the fighting vessels themselves, all of which have a powerful permanent ram bow stoutly supported by the horizontal armor deck or armor belt. The first Advisory Board recommended that rams should form a part of our fleet, and the present Advisory Board has submitted the general features for one, but it was found necessary to give the vessel a displacement of 3,000 tons so as to ensure a draught of water sufficient to enable the ram to operate below the armor belt of an armored vessel.

In referring to the armaments of the numerous classes of vessels which now form a modern fleet, we find that there are none that do not have a number of machine-revolving and rapid-firing single-shot guns as a portion of the battery. So general is this application, that every ship carrying large guns now has two batteries, and in speaking of them they are indicated as the primary and secondary batteries. No modern cruiser or armored vessel would be complete without this secondary battery. They are considered necessary in general action for clearing open decks, for entrance through portholes, and, as their penetration is very satisfactory at long distances, for the damage they can do after perforating the sides of unarmored vessels; they are also handy guns for use in tops, and are indispensable for protection against boat attacks by boarding and by torpedoes. This aid to the primary battery is regarded as an established provision for a modern battle ship.

Accepting the correctness of this conclusion as applied to ships armed with modern artillery, how much more does it apply to ships armed with guns which are not fitted to answer the demands of modern warfare?

I was particularly impressed with this conviction during a late visit on inspection duty to the U. S. S. Brooklyn, just fitted for sea. I found the old historic ship in good order, well officered, and with a young and hearty crew. Although she had been but five days from the navy-yard her organization was complete, and drills were already commenced; but as I stood on her poop deck and looked down on a fine body of men at their quarters, standing by their 9-inch smooth-bore guns, my mind instinctively jumped to the contemplation of action, and I pictured to myself the scene if engaged with an enemy armed with modern artillery, and with speed that would prevent the Brooklyn coming to close quarters, the only position in which her battery could be effective. I could recognize no hope in such a contest. The Brooklyn has, besides her smooth-bore 8-in. guns, one 8-in, converted rifle, one 60-pounder rifle, and four 37-millimeter Hotchkiss revolving cannon. The first two guns would be moderately effective at long range, but the 37-millimeter guns are only of use to guard the sides of the ship against torpedo-boat attack. I felt that here, if anywhere, and more than anywhere else, was a need for the largest rapid-firing single-shot guns. The 57-millimeter Hotchkiss gun, throwing a shell of six pounds weight, with a sufficient bursting charge, could be used to great advantage; its penetration at 1,000 yards is sufficient to penetrate two inches of iron, and it would, without doubt, perforate the side of any unarmored vessel, and it would give encouragement to the men to feel that there were some means in their power by which they could give back the blows they were receiving.

While we remain in our present helpless condition in respect to our primary batteries, I think that a great effort should be made to increase the power of our secondary batteries; our ships should be supplied with as many of the 57-millimeter Hotchkiss single-shot guns as can be accommodated, the 47-millimeter guns should be put in the tops. This gun can also be utilized as a boat gun for cutters that are now provided with no boat armament. The 37-millimeter revolving Hotchkiss cannon is undoubtedly the gun most efficient for repelling boat and torpedo attacks, and the Gatling gun is indispensable for use on shore with landing parties, but for the secondary batteries of ships for purposes of general action, and for the protection and encouragement of men stationed at our smooth-bore guns, we should place in position as many of the largest sized single-shot rapid-firing Hotchkiss guns as can be accommodated.

This involves, I well know, the question of stowage, for the amount of ammunition for these guns must be liberal. Imaginary established rights to space and store rooms will have to yield to the necessity of the chief want, and much that is now considered necessary in other departments may be found to be superfluous. Fortunately, in our old-fashioned ships the aggregate of the space for stowage is ample, and a judicious curtailing of space occupied by other departments will, without doubt, result in accommodating to ammunition required to make the secondary battery effective.

STEAM ENGINEERING.

Equally important with ships and guns are all matters pertaining to steam engineering. Fortunately our coast trade and the navigation of our inland waters has saved us from being unable to build engines and boilers, and in this respect we may feel that we are equipped to such a point as will make only supplementary such improvements as may be found necessary when the reconstruction of the Navy shall assume an earnest character, on this subject, however, I shall allude, with deference, to two matters which I consider well worthy the thought and attention of those charged with the important duty of designing and building our engines and boilers. One is the weight of our engines, the other is the necessity of a new type of steam generators.

In determining the general features of a vessel of war of a given displacement, the first question is as to the weight of the boilers and engines. If a certain speed is required, and the engineer declares that a certain weight of engines and boilers is necessary to produce it, it must be yielded to him, as he is responsible for the horse-power to be developed. The constructor, ordnance and equipment officers must do the best they can with what is left of the displacement. I do not think that sufficient attention has been paid to reducing the weights of our engines. I am the more confirmed in this opinion by the comparison of the weights of engines in ships lately built abroad with those assigned to our vessels of similar displacement.

I am aware that it has been the habit of some engineer officers to read these statements with reserve, to accept them with certain grains of allowance; as, for example, it is said that many things which are entered in the sum of weights with us are not so entered abroad, such as fire-room floors, platforms, ladders, spare parts, etc., all the appurtenances. It is said that the published weights comprise nothing but the actual engines and boilers themselves. I have never investigated the basis on which these reports are made, consequently am in no position to allow or to disprove this assertion, but my mind has never been satisfied that the reason was satisfactory. It seems to me more natural to take the reports as expressing what they purport to do. I believe that by careful study of this detail we can reduce weights; no one will deny that we can reduce weights very much by substituting steel for iron in many parts of our engines, as the superior strength of the steel will allow of very much reduced dimensions.

But how much more can these weights be reduced if a multitubulous boiler be adopted as the steam generator? We are now brought face to face with a positive demand for great speeds; ordinary speeds will not satisfy the demands of the times.

This can only be produced by increased power developed at the screw, which means an increased supply of steam to the engines. With the Scotch boiler, this means a multiplication of the number of boilers in order to obtain the increased grate surface, and a consequent large increase in the weight of the boilers and water to be carried.

At present, in order to avoid the necessity of carrying so much weight, only made necessary at the highest speeds, abnormal means, as forced draught, have to be resorted to. The fire room is closed. The blowers worked with great violence, and the furnace, combustion chamber, up-take and smoke-pipe are converted into parts of a blast furnace, the effect of which is to burn up and destroy rapidly all parts that are not surrounded by water. It seems to me that when we have reached the point where it is necessary to destroy the boiler in order to obtain the power demanded, it is time to look for a new steam generator. I am presenting no new idea, but I wish to emphasize the necessity of this effort, and to suggest to this Institute and to the Navy, the necessity of action in this matter.

The two more familiar types of multitubulous boilers for sea-going vessels are the Herreshoff and the Belleville boilers. I hazard no description of them; they are familiar to you. They have been going through a state of probation for several years. Mr. Herreshoff has increased the size of his boats which carry this boiler, until he has a vessel of 94 ft. in length, 11 ft. beam, 28 tons displacement, $4\frac{1}{2}$ ft. draught aft, and 3 ft. forward, with which he has obtained a speed of 21 knots per hour. The French Government has experimented with the Belleville boiler, and the performance of the dispatch boat Voltigeur, recounted in a paper published by this Institute in 1883, is well worth attention, for it conveys undeniable testimony of the success of the experiment; and, in fact, the trial in May last, of the French dispatch boat Milan, of 1,560 tons displacement, 303 ft. in length, and 33 ft. beam, takes the matter out of the region of experiment, and exhibits the Belleville boiler as an accomplished success. This vessel, on a draught of water of 12 ft., has attained a speed of 18.4 knots, with a developed horse-power of 4,000.

The Herreshoff and the Belleville are the only tubulous boilers that I know of that have as yet been applied to sea purposes, but we have the Babcock and Wilcox, and the Moore boilers of the same general character and type which are in use for stationary purposes, for heating or for working stationary engines, and no doubt these can be successfully applied to sea purposes by introducing modifications that would be found necessary in the new sphere of usefulness.

I will not attempt to institute comparisons, nor to discuss the details nor proportions of various types of boilers, but wish to emphasize the importance of a careful examination of a subject which promises to produce a safe and desirable marine boiler, with a reduction of weight of 30 to 50 per cent. over the Scotch type, thus adding enormously to the total efficiency of a ship.

The designing of a small gunboat is now under consideration at the Navy Department. Her displacement is fixed at 800 tons. If the same conditions obtain as in the cases of proportional weight cited above, nearly one-sixth of this will be devoted to providing for the weights of her boilers and engines, and a tenth to the accommodation of coal, thus appropriating about one-fourth of the entire displacement. This is probably the best that can be done with the present type of boiler. The ever-increasing demand for storage for ordnance supplies, consequent upon the large charges of powder now used, and the space needed for the stowage of ammunition for the secondary batteries, has reduced the equipment outfit to a minimum, has contracted the dimensions of the hold so that provisions can only be carried for a limited period, and seriously curtails the living spaces for the crew. A lightening of weights must be brought about in every department, and special efforts should be made in those appertaining to the engines and boilers. If the law authorizing the new vessels did not preclude anything in the nature of an experiment, I don't hesitate to say that I would like to see the first experiment in this direction made on this new gunboat; if the result were to be a total failure, I should consider it cheap experience. And it is well to mention just here another advantage attending these multitubulous boilers—that there is no trouble in removing them, as they are arranged in sections which can be renewed without tearing the ship to pieces by taking up decks. This concludes what I have to say on this subject. It may be that I underestimate some of the difficulties which I know exist in making this new departure, but in consideration of the advantages that will ensue from a successful application of this steam generator, I think they are worth the effort.

HYDROGRAPHIC OFFICE.

After touching on subjects on which our Navy is deficient, it is a relief to turn to one branch of the service where our advance is not only creditable, but promises to equal, if not to surpass, the development of similar work in foreign Governments. I allude to the Hydrographic Office.

A large number of officers are connected with this office, but the work is of such a character that it does not force itself so much on the attention of the service as do other branches. Its primary work is to supply our ships with charts and to carry on original surveys out of the waters of the United States; but the duties to effect this are multifarious, and a very perfect organization is necessary in order to guard against errors or oversights, which might produce very serious results. This office must be sure that, in distributing charts and sailing directions, it has the latest and most trustworthy information; accuracy is indispensable in the charts by which a ship is navigated. It is customary to place implicit confidence in a chart, unless warned of inaccuracies, and the responsibility of accident falls on the Hydrographic Office if reasonable precautions have been taken by the ship. It is thus very important to be able to trace error to its source, and in the organization of this office every precaution is taken to ensure this personal responsibility. It is impossible to assert that no error can occur in any system, however perfect it may seem to be, and however faithfully the agents may work; but where a system is so arranged that an error is sure to be traced back to the person responsible there is no doubt that a special guard against inaccuracies has been secured. The checks that are introduced in this respect in the Hydrographic Office secure this personal responsibility, and it must inspire much confidence in the work of the office.

The office is in correspondence with all similar institutions in the world, also with our ships of war and the United States consuls in the seaboard countries, and no chart is issued until all known charts of the region have been consulted, and all information has been collected from every available source.

At present the larger portion of charts issued to the Navy are purchased abroad, the British Admiralty charts being in the largest proportion. In fact, the Navy is practically dependent now on Admiralty charts, which form 85 per cent. of the chart outfit of a cruiser on the European station, 76 per cent. on the Asiatic, 30 per cent. on the Pacific, 40 per cent. on the South Atlantic, and even 25 per cent. on the North Atlantic station. Corrections are being constantly made and new charts purchased, but the ultimate object of the Hydrographic Office must be to make itself independent of foreign purchases, and equip itself with its own original plates of all the waters of the world. We have only to imagine a state of war to recognize at once the necessity of thus providing ourselves. Of course, the plates must be electrotyped for printing purposes, all of which requires time and money. This necessity is recognized by the present accomplished and energetic hydrographer of the Navy, and small sums each year are devoted to this purpose as they can be spared from current expenses, but the work should be separately provided for as a distinct object, and appropriations made accordingly. It must be remembered that this need exists not only for the Navy, but for the merchant marine, which is forced to purchase its foreign charts of dealers, who naturally sell to them charts of old date as long as any of the old stock is on hand.

The number of the original plates now in the possession of the Hydrographic Office is about 350, and quite a number of them are electrotyped, but when we consider that the number of charts required for navigating all the waters of the world now reaches over 3,000, we see that there is much labor yet in store for the office before we can be considered independent in this matter. All other nations of any importance are entirely independent in this respect, and the thorough organization that now obtains in our office justifies this consideration for it.

All other details appertaining to such an institution are carefully worked out. Sailing directions always corrected to date and notices to mariners are issued with dispatch, and our consuls abroad are kept informed of all that transpires necessary to be communicated to our merchantmen abroad.

One of the best proofs of the practical value of the Hydrographic Office is the favor with which it is regarded by our merchants and merchant captains. The establishment in our principal seaports of branch offices has had much to do in calling its usefulness into notice. It is found now that ship captains bring their charts to these offices for verification and correction, and many are surprised to find that new editions of their charts showing quite different hydrographic conditions have long since supplanted those which they were using. The notices to mariners, also, which give immediate notice of newly-discovered dangers, are thus more rapidly communicated to those who are the most interested in them. The interests of ship captains, thus aroused, works now to the advantage of the office itself, for it is in constant receipt of information communicated by those who have been benefited by its operations. The sale of the hydrographic charts has also increased to a great extent.

A striking feature in the work of this office is the monthly issue of the pilot chart of the North Atlantic Ocean, which presents graphically any information relating to the North Atlantic of interest and value to mariners. There appears on the chart a statement of the information collected during the month preceding, and a forecast of what may be expected during the month following. This chart is carried by all Trans-Atlantic steamers, and many of them are sailed in accordance with its instructions. The prevailing winds, the position of icebergs and that of wrecks along this highway of the ocean are items of knowledge much needed by the navigator, and it is expected that the observations now being collected will enable the office, in a short time, to lay down a very close approximate limit of fogs during the different seasons of the year which will be a valuable addition to the present guards against accidents.

We can congratulate ourselves on the creditable and most useful work that is being done by this branch of the Navy Department, and it is to be hoped that our present able hydrographer may be encouraged in his work by liberal appropriations to enable him to make the Government independent of foreign aid in the supply of charts.

I have finished the work that I set myself to perform. With the exception of the Hydrographic Office, which I recognize as established on a sound basis and only needing appropriations of money to make it independent of foreign aid, the subjects on which I have touched are those in which we are most deficient. I have confined myself to them as being the essential ones to be borne in mind as needing attention in the work of rehabilitation. The main object of my address is to preach encouragement to those who are left to occupy the field of action. The chance for speedy restoration to the position that the Navy once occupied is not cheering at present, but we have cause for encouragement in the fact that the first steps have been taken, and it is the first step that always costs the most effort. We have the right to recognize that the advance has commenced, and it is the duty of every individual member of the service to prepare to do his share in aiding the movement.

As I said before, notwithstanding the decadence of the *materiel* of the Navy, we have reason to be proud of the condition of its personnel, and we feel confident that it embodies talent capable of treating the many questions of science and practice that are to be encountered. These involve much work, and demand thorough knowledge of the subjects to be treated, and I am tempted to emphasize the source from which the Navy, at this time of trial and exacting requirement, draws the strength which enables it to respond to the call made upon it. The source of power is in the Naval Academy, which has saved the Navy. The portion of knowledge there acquired has expanded the minds of its graduates, and their habits of study have enabled them to go on and better their instruction. The result has been the wide dissemination in the service of advanced ideas which keep pace with progress and fit the officers for the work they are called upon to perform.

I have the honor of being the senior graduate from the Naval School at Annapolis, but I did not enjoy the advantage of the academic course, which came after my time. I claim it, however, as my Alma Mater, and I take as much pride in it as do those of younger classes; and, in concluding my remarks, I would say to all graduates that, while we cling with affectionate memory to the associations that surround the Academy, and while we love to share with it the credit that its graduates have achieved, we should not forget him to whom we owe the gift, we should ever keep green the memory of its founder. It was the Honorable George Bancroft who, when charged in 1845 with the care of the naval branch of the service, looked ahead into the future, and foreseeing the march of progress, and well appreciating the needs of *education*, conferred upon the Navy that ineffable boon, the full advantage of which we now reap. This revered sage still goes out and in among us, loaded with years and honors that a grateful people has bestowed, and occupying his time in still further adding to his enviable reputation in the present, and rearing a literary monument which will preserve his memory to posterity; but no class of his countrymen have so much cause to respect and honor him, or have so strong a reason for gratitude to him as have the officers of the Navy.

THE NAVY QUESTION.

By LIEUTENANT BRADLEY A. FISKE, United States Navy.

Written for VAN NOSTRAND'S MAGAZINE.

THE people of the United States are better fitted to build a modern Navy than any other people in the world. They are inventive, constructive, executive, persevering, enterprising and rich. The same circumstances which have produced Morse, Dahlgren, Ericcson and Edison; the same characteristics which have placed them ahead of all other nations in applying science to practical affairs and in pushing through great enterprises, would enable them to build a Navy of a higher type than any the world has yet seen.

A Navy at the present day is an organization comprising floating fighting machines of various kinds, and a number of men capable of handling them; and it is clear that ships, guns and torpedoes, together with the apparatus by which they are controlled, are in reality machines or tools adapted to special work, but constructed and operated on the same principles as govern all machines, tools, engines and structures.

So, the modern Naval profession has become a branch of the broad science of Engineering, advancing as that science advances, and contributing in turn to the progress of Engineering by each invention made and principle discovered in Naval science; for, since the principles of mechanics, mathematics, physics and chemistry underlie all branches of engineering, a step in one branch affects all the other branches.

The happy result attending the close relationship which has thus sprung up between naval science and engineering, is clearly to place the Navy more within the sympathies of the people; for since engineering, including civil engineering, steam engineering, sanitary engineering, mining engineering, electric engineering, metallurgy, chemistry, &c., is very closely identified with the interests of the people, the interests of the Navy are clearly becoming closely identified with the interests of the people, even in time of peace.

Now, the idea that the interests of the Navy can be in accord with the interests of the people, in time of peace, is not generally held; and a prominent paper went so far, a few days since, as to say that the interests of the Navy were opposed to the interests of the people. While, too, the maintenance of a small but efficient Navy is approved by most men, it is nevertheless considered a disagreeable necessity, and one entailing an enormous expense, allowable only because it may save a greater expense in time of war; and as most people have read Marryat, the Naval man appears to their imagination as a man apart from other men, full of strange sea-slang, horribly profane, chewing tobacco, bow-legged and usually drunk.

A very brief consideration, will show, it is believed, that the interests of the Navy are closely allied to the interests of the people, instead of opposed to them; so that the building of a suitable Navy would not benefit the Navy alone, but the people also.

The work of the Navy in aiding navigation along the coast and on the high seas, and in publishing books and charts for mariners, need not be mentioned, for this is well understood; but the good which would be done in the interior of the country by constructing a suitable Navy is not generally understood.

Perhaps the most direct good done would be the stimulation of the iron industry, and the unquestioned improvement which would follow in the manufacture of steel. The construction of a number of ships sufficient to act as an insurance on our property near the coasts, would benefit, not only the men engaged in the actual building of the ships, but also the men engaged in the mines, in the transportation of the ore from the mines, in the reduction of the ore in blast furnaces, in the making of steel, in the forging of large masses of steel, and in the fabrication of these masses into engines, armor plates, guns, gun-carriages, &c.

And the ordering of large forgings of the finest steel by the Navy Department, would justify capitalists in making the most elaborate and costly experiments looking to improvements in the quality of steel, to a cheapening of the methods of its production, and to a solution of certain problems as to the nature of steel, which would enable them to turn out steel of any desired combination of physical characteristics, such as tensile strength, elastic strength, elongation, &c., with unfailing precision. The necessary hammers and presses also which capitalists would erect, to furnish the navy with large forgings, would enable them to produce large masses of steel for other purposes, such as the building of machinery and of large structures throughout the country.

But we must not suppose that it would be only by the direct means of the employment of hundreds of thousands of men and the improvement in steel-making that the prosperity of the Navy would increase the prosperity of the country, for we must not forget that, by reason of the close relation now borne by Naval science to engineering and to the scientific work of the country, any improvement in ships, guns, engines and apparatus is at once felt all over the land.

Take the science of steam engineering, for example. No one can hold that improvements, inventions and discoveries in this science do not benefit the whole country, for steam engines are used everywhere, their use is daily increasing, and the principles underlying the construction and operation of all steam engines and boilers are the same, no matter to what special purpose any special kind of engine or boiler may be applied. Now, many of the most important improvements in engines and boilers have been brought about by the requirements of war ships, but the fact of an improved type of engine or boiler having been first used in a war ship has not prevented that improved type of engine or boiler from being used in merchant ships afterwards. A few years ago a steam pressure of thirty pounds per square inch was thought enormous, but now there are torpedo boats abroad which are run with 150 lbs. pressure, with proportionate increase of horse-power per pound of coal; and multitubular boilers have been made to work at a pressure of 500 lbs., expending only a little more than a pound of coal per horse-power per hour. It seems a very short time ago also that compound engines were first tried, in which the steam after doing its work in one cylinder in forcing the piston to one end of its stroke, was exhausted into another cylinder, and did similar work there at a lower pressure—and now we hear of engines in which the steam is made to expand in four cylinders in succession before it is allowed to exhaust into the condenser.

In every country, let it be borne in mind, in which great progress has been made in steam engineering, a very large part of the incentive has been the inducement held out by the Government to builders of the best engines for war ships; and the reason that the United States has dropped so far behind England and France in engine building is simply that the Royal Navy and the French Navy have advanced and the United States Navy has not.

The struggling science of electric lighting also has been aided largely by Naval patronage, for in Europe and to some extent in this country, electric companies have received much substantial encouragement in the shape of orders for lighting war ships; and the tests of dynamos and incandescent lamps upon which the most reliance is placed all over the world, are those undertaken for the Franklin Institute by a Committee which consisted for the most part of Navy and Army officers whose chairman was a young officer in our Navy.

Certainly it will not take much consideration to show us that in the matter of ship construction, too, the interests of the Navy and the people are identical, for we can see at once that the plant needed for building steel war ships and the experience gained in building them would enable shipbuilders to improve and to cheapen the construction of steel merchant ships and even of boats. A comparatively small reduction in the price of steel plates would permit the construction of steel ships and boats at about the present price of wooden ships and boats. Steel schooners for instance could be built instead of wooden ones, and besides being more durable and strong, they would cost less for repairs.

Even in the line of explosives we can see that the requirements of modern warfare have contributed to the march of civilization and to the comfort and happiness of mankind, for the most reliable experiments made with explosives have been made with a view to developing weapons of destruction; and yet the conclusions reached and the improvements made have put means in the grasp of the engineer, the miner and the pioneer for blasting through solid rock with speed and safety.

That a close sympathy exists between the Naval profession and other branches of engineering is shown by the very numerous applications to warfare that are made of new discoveries, and by the fact that the sciences of steam engineering, shipbuilding, ordnance, &c, keep pace with the rapid advance of kindred sciences. New developments are constantly appearing. In steam engineering the rapid increase in the pressure at which steam is carried, in the quantity of coal burned per square foot of grate surface, rendered possible by the increasing use of the forced draught, coupled with great decrease in the weight of engines and boilers—all show that we are approaching speeds in ocean steamers that were undreamed of a few years ago. The progress going on in ordnance is more rapid still: ranges are increasing fast, and projectiles are growing rapidly in weight, and as yet we can see no limit, either to range or to weight of projectile. The science of ordnance is evidently in its infancy, especially in the matters of projecting large masses of high explosives through the air, and in swiftly and accurately propelling auto-mobile torpedoes under water. The application of electricity to ordnance is just beginning to throw its shadow before; for though we see it now used for firing guns and torpedoes, and for steering and propelling torpedoes at a distance, it is evident that it will soon have a larger field and be used for pointing great guns with speed and precision, and for communicating between vessels at sea without wires. The machine gun already fires 1,000 bullets per minute; the revolving cannon fires with good aim twenty shell per minute, each shell weighing about four pounds, and the light rapid fire gun fires fifteen shell per minute with good aim, each shell weighing six pounds and capable of piercing four inches of iron. All of these guns operate by hand, and are nearly automatic; but the Maxim gun introduced into England is absolutely automatic, the recoil of one shot furnishing the energy for loading and firing the next, &c. The problem of swiftly turning steamers is being rapidly worked out, some torpedo boats abroad being now able to turn within their own length. And we have just heard of a new explosive that promises to surpass nitroglycerine.

But this rapid improvement in all branches of Naval science cannot continue without continued study and experiment. Now that Congress has decided that we ought to have an efficient Navy, let us hope that Congress and the country will not suppose that progress has come to a stand-still, and that we must stick fast to what has thus far been done abroad; for progress is marching with rapid steps, and the natural inventiveness of Americans will give us a great superiority over all other nations, if we only profit by it.

The reverse plan has, however, been followed in this country for the past twenty years, and many American inventors after having been discouraged or ignored by their own Government, have gone to Europe and received substantial encouragement, so that many of the best systems in use to-day by foreign powers are the invention of American citizens. Clearly, "these things ought not so to be."

If we are content to follow where our natural genius shows that we should lead, we may attain certain results at a less cost of money than if we undertook experiments ourselves; but we shall always keep about two years behind other powers, so that in case of war we shall find ourselves at a proportionate disadvantage; and, besides, we shall never rise to so high an excellence as we should by properly encouraging American inventors to turn their thoughts to means for protecting their own country. Moreover, the inducements held out by the Government to inventors would operate not only to give the Navy improved apparatus and machinery, but would also stimulate study of practical science all over the country and tend to enhance our material prosperity.

In case, however, we do not attempt progress, but stick fast to what has been done in England, refusing to spend money in experiments and fearing to make mistakes, so that our ships, guns and engines will be virtually English, and in case one of these ships meets an English ship and whips her, let us not forget to give due credit—to England.

In view of the considerations urged above, showing that a dollar spent in the Navy is not a dollar wasted, provided it be spent within the United States, let us hope that Congress in building an "efficient Navy" will build a large Navy. It is common to hear the opinion advanced that we need a good Navy but not a large one; that it would be opposed to our interests and contrary to our policy as a Republic to have a large Navy; and we hear it argued that what we need is a few good ships which could in time of war, serve as a nucleus around which as large a Navy could be constructed as the war might demand. This reasoning is fallacious; it would not have been fallacious twenty years ago, but it is fallacious now. Precisely the same causes as renders it wise for us to have a good Navy render it wise for us to have a large Navy.

The reasons why we need a good Navy are that our coast exposes a great many billions of dollars worth of property to anybody who chooses to destroy it; and that the great speed of modern ships, the great thickness of their armor, and the great range of their guns, together with the existence of cables under all the seas, enable any European country (and some South American countries) to concentrate a large fleet on our coasts and bombard our towns—in three weeks after declaration of war. How could a small but good Navy serve as a nucleus at such a time? Under the very best circumstances could this nucleus be developed into a sufficient Navy in three weeks?

It would require two years at least. And after the new Navy had been built, comprising large ironclads with suitable engines, guns, &c., whom would we get to manage them? Where would we get men capable of properly handling and fighting these monstrous machines full of elaborate engines, of guns of a great many types, controlled by complicated apparatus, of torpedoes, of gun-cotton, and other high explosives, &c? We could not find them in the Navy, because, granting that all the men in the Navy had not long since been killed, we only had enough men originally in the Navy for the nucleus; and the drafting of several thousand men at hazard, and the putting of them on board modern ships to manage their electrical apparatus and gun-cotton might, perhaps, be a very interesting experiment, but it can hardly be prophesied in advance that it would be a successful one.

It must be plain that the expression "a small but efficient Navy" is meaningless, because a Navy cannot for our purpose be efficient if it is small. A Navy to be efficient must fullfil the purpose for which it is intended, and as the principal purpose for which our Navy is intended is to protect our coasts against a sudden attack by a large modern fleet, it cannot be efficient unless it can repel that attack; and to do this it must comprise a great number of armored ships, equipped with the best and latest apparatus and manned with officers and men capable of handling that apparatus.

ADVANTAGES OF NARROW-GAUGE RAILWAYS.

By AUGUSTE MOREAU.

From "Iron."

The author has for some years devoted much attention to the subject of narrow-gauge railways, and their suitability for accommodating the traffic requirements of more or less thinly-populated districts, by putting them in railway communication with the main lines. Although these railways are especially adapted to districts where the traffic is limited, they are also capable of carrying an amount —in some instances very considerable, as on the Festiniog (North Wales) Railway, where with a gauge of only two feet, the traffic receipts are £2,253 per mile per annum. This compares favorably with the State Railway of France, a line of normal gauge (4 feet 8½ inches), earning £644 per mile. As regards speed, that obtained upon the Festiniog Railway is 31 miles per hour, and, according to Mr. Fairlie, could with safety be increased to 45 miles per hour.

In France, since 1881, concessions have been granted for more than 1,864 miles of railways in outlying districts (Chemins de Fer d'intérêt local), and, in the author's opinion, there remain ten times that amount yet to be constructed of lines necessary for bringing the villages of various districts into communication with the neighboring towns and the main railway systems. These railways, however, to be remunerative, must be constructed to a gauge much less in width than that of the normal 4 feet 8½ inches, as a return of from £193 to £257 per mile per annum is at the present time regarded as a fair amount of traffic for a local line.

The cost of some of the narrow-gauge lines in other countries is given. In Norway, with a gauge of 3 feet 6 inches, the cost has varied from £3,154 to £5,342 per mile, according to the character of the country. In Sweden, where all the lines are narrow.gauge, varying from 2 feet 7 inches to 4 feet, the cost has averaged £3,862 per mile. In Brazil four-fifths of the railways are on a reduced gauge, varying from 2 feet 6 inches to 4 feet 6 inches in width, the greater part of these being to the 3 feet 3 inches (1 meter) gauge. and extending over a length of 2,983 miles. The remaining fifth (Dom Pedro II.) is to a gauge of 5 feet 3 inches (1.60 meter). The average traffic receipts of the narrow-gauge railways are £1,287 per mile per annum.

In Canada there is a length of 870 miles of railway laid to a gauge of 3 feet 6 inches. The cost of the Toronto, Grey & Bruce, forming part of this system, was, without rolling stock, £1,287 per mile. In Queensland some of the railways are of 3 feet 6 inches gauge, the speed being from 15½ to 18½ miles per hour, and the cost of construction from £5,986 to £9,977 per mile. The Ergastirian Railway (Greece), with a gauge of 3 feet 3 inches, cost, complete, £4,814 per mile, in a country so rough as to necessitate tunneling. Details are given of the permanent way and rolling stock used on the narrow gauge (2 feet 7 inches) railway between Rupertshof and Hennef, near Cologne, but the cost is not mentioned. In the French colonies the 3 feet 3 inches gauge is generally adopted, and the secondary lines of Algeria, of which there are about 3,760 miles yet to construct, will be to that gauge. A table is given showing the widths of the principal narrow-gauge lines in work or under construction in France and elsewhere, from which it may be seen that the reduced gauge most prevalent in France is 3 feet 3 inches; in Germany, 2 feet 6 inches; and in England, or those countries subject to English influence, 3 feet or 3 feet 6 inches.

The author recommends that the width of gauge best suited for adoption in constructing local lines will, with few exceptions, viz., in very thinly populated districts, where the gauge might be made 2 feet 6 inches, be found to be 3 feet 3 inches, and describes at length the economical advantages of this gauge as compared with that of the normal, viz., 4 feet 8½ inches. In earthwork the great saving is due partly to the reduction of the formation width, but in hilly districts far more to the avoidance of heavy embankments and cuttings, through being enabled more closely to follow the natural surface of the ground, by the adoption of curves of very much sharper radius, and gradients of greater inclination. The author also demonstrates that with a gauge of 3 feet 3 inches the rolling stock can with equal ease travel over a curve of less than half the radius of the equivalent curve on the normal gauge, and that the proportion of dead load to useful load in the rolling stock, being diminished in the case of the reduced gauge, therefore the inclination of the gradients may be made steeper.

The above considerations directly influence the area of land required, and a further saving under this head is effected by the avoidance of a severance, and a reduction in the length of road and steam, diversions, &c. Bridges and culverts are similarly reduced in cube, and in many instances their necessity avoided, and the saving extends to workshops, carriage and engine sheds. As regards the permanent way, the weight of the locomotives being only from 4 to 6 tons per axle, a rail weighing from 50 to 60 lbs. per yard suffices, and the sleepers are reduced from 8 feet 3 inches to a length of 5 feet three inches or 5 feet 11 inches, and are proportionately less in cross section.

In the rolling stock the advantage procured by the adoption of the 3 feet 3 inches gauge, in diminishing the proportion of the dead to the useful load, is demonstrated as follows. Supposing all the dimensions of the two rolling stocks to be in the same proportion as the gauges, then the weight of the respective wagons will be as the cube of the gauges $\frac{p}{P}=\frac{3'\,3''^3}{4.8\frac{1}{2}^3}\left(\frac{1.000^3}{1.445^3}\right)=\frac{1}{3}$ about, and the molecular resistance to flexure will be as the squares of the corresponding dimensions, $\frac{R}{r}=\frac{3'.3''^2}{4\,8\frac{1}{2}^2}\left(\frac{1.000^2}{1.445^2}\right)=\frac{1}{2}$ about. Therefore the wagon of the 3 feet 3 inches gauge will only weigh one-third of that of the 4 feet 8½ inches gauge, but will be capable of carrying one-half the load of the latter. Dividing these into one another, $\frac{1}{3}\div\frac{1}{2}=\frac{2}{3}$, therefore the portion of the dead to the useful load for a gauge of 3 feet 3 inches is two-thirds (0.666) only of what it would be for the normal gauge. In practice the diminution in the dimensions as above described cannot be strictly carried out, but the proportion of the dead to the useful load may, in the 1 meter gauge, be assumed as 0.7 of that for the normal gauge.

The author states that in England goods wagons capable of carrying 8 tons average a useful load of only 1 ton, and that, as regards passenger traffic, the number of persons actually carried is twenty-five for every one hundred seats provided. In France, as regards the goods traffic, the discrepancy is less marked, the average being 4 tons of dead weight to 1 ton of useful load; but the proportion of passengers is about the same as in England. In addition to the saving in dead-weight, the wagons of the 3 feet 3 inches gauge are also better adapted for a local traffic where the separate consignments are likely to be small in amount. The passenger carriages of the 3 feet 3 inches gauge may with safety be made 9 feet 2 inches wide, thus affording five seats in each transverse row. A single central buffer is strongly recommended for narrow-gauge vehicles, as better adapted for sharp curves. It has been suggested that the normal gauge might be preserved, and at the same time the cost of construction in rough countries be reduced to a minimum, by adopting sharp curves, worked with rolling stock of the American bogie truck type, but one great objection to this is the increase in the dead-weight of the vehicles, the proportion being 8 to 1 (with a full carriage), as compared with 3 to 1 on the 3 feet 3 inches gauge. The objections to the break of gauge, on account of the trans-shipment, may be classified under the heads of working expenses, delay, and damage to goods. The first may be diminished to a cost of ½d. per ton, if proper arrangements are instituted. The question of delay is of little importance, as, where there is no break of gauge a day is usually lost when a truck has to pass from one system to another. With regard to damage, the higher classes of goods being as a rule in small consignments, they form only portion of a truck load, and therefore would, with an unbroken gauge, have to be transhipped at the junction; whereas, in the instance of coals and other minerals, coal, &c., their transhipment would, under this head, be of little import.

Under present conditions, at the junction of two systems similar in gauge, a transhipment always takes place of incomplete loads, and, in addition, three-fourths the amount of all merchandise arriving in full wagons.

The saving in cost of construction of a line through an easy country is at least equal to the proportionate diminution of the gauge—viz., 33 per cent., increased in a rough country to 50 per cent. or 75 per cent.

The following are the costs of a few narrow-gauge lines, compared with what they would have amounted to if constructed with the normal gauge:

	Normal Gauge.
1 meter gauge, Anzin to Calais, cost £4,956 per mile	(77,000 fr. per kilo.),
was estimated at £12,872	(200,060 fr. ").

	Normal Gauge.
1 meter gauge, Hermes to Beaumont, cost £4,956 per mile	(77,000 fr. per kilo.),
was estimated at £14,802	(230,000 fr. ").

Had the Corsican railways been constructed to the normal gauge, it was estimated that they would have cost from three to four times the amount actually expended upon the 3 feet 3 inches gauge.

In the Rio Grande (Denver) railway the narrow gauge cost three-fifths of what the normal would have, and the Livonia (Russian) railway, with a gauge of 3 feet 6 inches (1.067 meter), realized an economy of 40 per cent. on the estimate for the normal gauge.

In conclusion, in adopting narrow-gauge lines, the public should have every facility offered it for using them, including simplification of classes, stopping-places at the crossings of all important roads, and commissions should be given to the hotel and shop-keepers of the district for the sale of tickets. In France all the railways requiring the normal gauge have already been constructed, but there still remains an enormous length of narrow-gauge lines to be made, which, if carried out in an economical manner, would reduce the cost from £9,655 (150,000 fr.) to £12,172 per mile (200,000 fr. per kilometer) for the normal gauge, down to £3,218 or £5,150 per mile (50,000 per mile, or 80,000 per kilometer) for the 3 feet 3 inch gauge.—*Memoires de la Société des Ingénieurs Civils;* through *Proc. Inst. Civ. Eng.*

UNIVERSAL OR WORLD TIME.

Lecture by W. H. M. CHRISTIE, F.R.S., Astronomer-Royal, at the Royal Institution, March 19, 1886.

From "Nature."

Considering the natural conservatism of mankind in the matter of time-reckoning it may seem rather a bold thing to propose such a radical change as is involved in the title of my discourse. But in the course of the hour allotted to me this evening, I hope to bring forward some arguments which may serve to show that the proposal is not by any means so revolutionary as might be imagined at the first blush.

A great change in the habits of the civilized world has taken place since the old days when the most rapid means of conveyance from place to place was the stage coach, and minutes were of little importance. Each town or village then naturally kept its own time, which was regulated by the position of the sun in the sky. Sufficient accuracy for the ordinary purposes of village life could be obtained by means of the rather rude sun-dials which are still to be seen on country churches, and which served to keep the village clock in tolerable agreement with the sun. So long as the members of a community can be considered as stationary, the sun would naturally regulate, though in a rather imperperfect way, the hours of labor and of sleep and the times for meals, which constitute the most important epochs in village life. But the sun does not really hold a very despotic sway over ordinary life, and his own movements are characterized by sundry irregularities to which a well-ordered clock refuses to conform.

Without entering into detailed explanation of the so-called "Equation of Time," it will be sufficient here to state that, through the varying velocity of the earth in her orbit, and the inclination of that orbit to the ecliptic, the time of apparent noon, as indicated by the sun, is at certain times of the year fast, and at other times slow, as compared with 12 o'clock, or noon, by the clock. [The clock is supposed to be an ideally perfect clock, going uniformly throughout the year, the uniformity of its rate being tested by reference to the fixed stars.] In other words, the solar day, or the interval from one noon to the next by the sun, is at certain seasons of the year shorter than the average, and at others longer, and thus it comes about that by the accumulation of this error of going, the sun is, at the beginning of November, more than 16 minutes fast, and by the middle of February, 14½ minutes slow, having lost 31 minutes, or more than half-an-hour, in the interval. In passing, it may be mentioned as a result of this, that the afternoons in November are about half-an-hour shorter than the mornings, whilst in February the mornings are half-an hour shorter than the afternoons. In view of the importance attached by some astronomers to the use of exact local time in civil life, it would be interesting to know how many villagers have remarked this circumstance.

It is essential to bear these facts in mind when we have to consider the extent to which local time regulates the affairs of life, and the degree of sensitiveness of a community to a deviation of half-an-hour or more in the standard reckoning of time. My own experience is, that in districts which are not within the influence of railways, the clocks of neighboring villages commonly differ by half an hour or more. The degree of exactitude in the measurement of local time in such cases may be inferred from the circumstance that a minute hand is usually considered unnecessary. I have also found that, in rural districts on the Continent, arbitrary alterations of half-an-hour fast or slow are accepted, not only without protest, but with absolute indifference.

Even in this country, where more importance is attached to accurate time, I have found it a common practice, in outlying parts of Wales (where Greenwich time is about 20 minutes *fast* by local time) to keep the clock half-an hour fast by railway (*i. e.*, Greenwich) time, or about 50 minutes fast by local time. And the farmers appeared to have no difficulty in adapting their hours of labor and times of meals to a clock which, at certain times of the year, differed more than an hour from the sun.

There is a further irregularity about the sun's movements which makes him a very unsafe guide in any but tropical countries. He is given to indulging in a much larger amount of sleep in winter than is desirable for human beings who have to work for their living, and cannot hibernate as some of the lower animals do. To make up for this he rises at an inconveniently early hour in summer, and does not retire to rest until very late at night. Thus, it would seem that a clock of steady habits would be better suited to the genius of mankind.

Persons whose employment requires daylight must necessarily modify their hours of labor according to the season of the year, whilst those who can work by artificial light are practically independent of the vagaries of the sun. Those who work in collieries, factories, or mines, would doubtless be unconscious of a difference of half-an-hour or more between the clock and the sun, whilst agriculturists would practically be unaffected by it, as they cannot have fixed hours of labor in any case.

Having thus considered the regulating influence of the sun on ordinary life within the limits of a small community, we must now take account of the effect of business intercourse between different communities separated by distances which may range from a few miles to half the circumference of our globe. So long as the means of communication were slow, the motion of the traveler was insignificant compared with that due to the rotation of the earth, which gives us our measure of time. But it is otherwise now, as I will proceed to explain.

Owing to the rotation of the earth about its axis, the room in which we now are is moving eastward at the rate of about 600 miles an hour. If we were in an express train going eastward at a speed of 60 miles an hour (relatively to places on the earth's surface), the velocity of the traveler due to the combined motions would be 660 miles an hour, whilst if the train were going westward it would be only 540 miles. In other words. if local time be kept at the stations, the apparent time occupied in traveling 60 miles eastward would be 54 minutes, whilst in going 60 miles westward it would be 66 minutes. Thus, the journey from Paris to Berlin would apparently take an hour and a-half longer than the return journey, supposing the speed of the train to be the same in both cases.

In Germany, under the influence of certain astronomers, the system of local time has been developed to the extent of placing posts along the railways to mark out each minute of difference of time from Berlin.. Thus, there is an alteration of one minute in time, reckoning for every ten miles eastward or westward, and even with the low rate of speed of German trains, this can hardly be an unimportant quantity for the engine-drivers and guards, who have to alter their watches one minute for every ten miles they have traveled east or west. This would seem to be the *reductio ad absurdum* of local time.

In this country the difficulty as to the time reckoning to be used on railways was readily overcome by the adoption of of Greenwich time throughout Great Britain. The railways carried London (*i. e.*, Greenwich) time all over the country, and thus local time was gradually displaced. The public soon found that it was important to have correct railway time, and that even in the west of England, where local time is about twenty minutes behind Greenwich time, the discordance between the sun and the railway clock was of no practical consequence. It is true that for some years both the local and the railway times were shown on village clocks by means of two minute hands, but the complication of a dual system of reckoning time naturally produced inconvenience, and local time was gradually dropped. Similarly in France, Austria, Hungary, Italy, Sweden, &c., uniform time has been carried by the railways throughout each country. It is noteworthy that in Sweden the time of the meridian one hour east of Greenwich has been adopted as the standard, and that local time at the extreme east of Sweden differs from the standard by about 36½ minutes.

But in countries of great extent and longitude, such as the United States and Russia, the time-question was not so easily settled. It was in the United States and Canada that the complication of the numerous time standards then in use on the various railways forced attention to the matter. To Mr. Sandford Fleming, the constructor of the Inter-Colonial Railway of Canada, and engineer-in-chief of the Pacific Railway, belongs the credit of having originated the idea of a universal time to be used all over the world. In 1879 Mr. Fleming set forth his views on time-reckoning in a remarkable paper read before the Canadian Institute. In this he proposed the adoption of a universal day, commencing at Greenwich mean noon, or at midnight of a place on the anti-meridian of Greenwich, *i. e.*, in longitude 180° from Greenwich. The universal day thus proposed would coincide with the Greenwich astronomical day, instead of with the Greenwich civil day, which is adopted for general use in this country.

The American Metrological Society in the following year issued a report recommending that, as a provisional measure, the railways in the United States and Canada should use only five standard times, 4, 5, 6, 7, and 8 hours respectively later than Greenwich, a suggestion originally made in 1875 by Professor Benjamin Peirce. This was proposed as an improvement on the then existing state of affairs, when no fewer than seventy-five different local times were in use on the railroads, many of them not differing more than 1 or 2 minutes. But the committee regarded this merely as a step towards unification, and they urged that eventually one common standard should be used as railroad and telegraph time throughout the North American Continent, this national standard being the time of the meridian 6 hours west of Greenwich, so that North American time would be exactly 6 hours later than Greenwich time.

Thanks to the exertions of Mr. W. F. Allen, Secretary of the General Railway Time Convention, the first great practical step toward the unification of time was taken by the managers of the American railways on November 18, 1883, when the five time-standards above mentioned were adopted. Mr. Allen stated in October, 1884, that these times were already used on 97½ per cent. of all the miles of railway lines, and that nearly 85 per cent. of the total number of towns in the United States of over 10,000 inhabitants had adopted them.

I wish to call particular attention to the breadth of view thus evidenced by the managers of the American railways. By adopting a national meridian as the basis of their time-system, they might have rendered impracticable the idea of a universal time to be used by Europe as well as America. But they rose above national jealousies, and decided to have their time reckoning based on the meridian which was likely to suit the convenience of the greatest number, thus doing their utmost to promote uniformity of time throughout the world by setting an example of the sacrifice of human susceptibilities to general expediency.

Meanwhile Mr. Sandford Fleming's proposal had been discussed at the Geographical Congress at Venice in 1881, and at a meeting of the Geodetic Association at Rome, in 1883. Following on this a special conference was held at Washington in October, 1884, to fix on a meridian proper to be employed as a common zero of longitude and standard of time-reckoning throughout the globe. As the result of the deliberations it was decided to recommend the adoption of the meridian of Greenwich as the zero for longitude, and the Greenwich civil day (commencing at Greenwich midnight and reckoned from 0 to 24 hours) as the standard for time-reckoning. In making this selection the delegates were influenced by the consideration that the meridian of Greenwich was already used by an overwhelming majority of sailors of all nations, being adopted for purposes of navigation by the United States, Germany, Austria, Italy, &c. Further, the United States had recently adopted Greenwich as the basis of their time reckoning, and this circumstance in itself indicated that this was the only meridian on which the Eastern and Western Hemispheres were likely to agree.

The difficulties in the way of an agreement between the two hemispheres may be appreciated by the remarks of the Superintendent of the American Ephemeris on Mr. Sandford Fleming's scheme for universal time (which was subsequently adopted in its essentials at the Washington Conference): "A capital plan for use during the millenium. Too perfect for the present state of humanity. See no more reason for considering Europe in the matter than for considering the inhabitants of the planet Mars. No, we don't care for other nations; can't help them, and they can't help us."*

As a means of introducing universal time, it has been proposed by Mr. Sandford Fleming, Mr. W. F. Allen, and others, that standard times based on meridians differing by an exact number of hours from Greenwich should be used all over the world. In some cases it may be that a meridian differing by an exact number of half-hours from Greenwich would be more suitable for a country like Ireland, Switzerland, Greece, or New Zealand, through the middle of which such a meridian would pass, whilst one of the hourly meridians would lie altogether outside of it.

The scheme of hourly meridians, though valuable as a step towards uniform time, can only be considered a provisional arrangement, and though it may work well in countries like England, France, Italy, Austria, Hungary, Sweden, &c., which do not extend over more than one hour of longitude, in the case of such an extensive territory as the United States difficulties arise in the transition from one hour section to the next, which are only less annoying than those formerly experienced, because the number of transitions has been reduced from seventy-five to five, and the change of

* Proceedings of the Canadian Institute, Toronto, No. 143, July, 1885.

time has been made so large that there is less risk of its being overlooked. The natural inference from this is that one time-reckoning should be used throughout the whole country, and thus we are led to look forward to the adoption in the near future of a national standard time, 6 hours slow by Greenwich, for railways and telegraphs throughout North America.

We may then naturally expect that by the same process which we have witnessed in England, France, Italy, Sweden, and other countries, railway time will eventually regulate all the affairs of ordinary life. There may, of course, be legal difficulties arising from the change of time reckoning, and probably in the first instance local time would be held to be the legal time, unless otherwise specified.

It seems certain that when a single standard of time has been adopted by the railways throughout such a large tract of country as North America, where we have a difference of local time exceeding five hours, the transition to universal time will be but a small step.

But it is when we come to consider the influence of telegraphs on business life, an influence which is constantly exercised, and which is year by year increasing, that the necessity for a universal or world time becomes even more apparent. As far as railways are concerned, each county has its own system, which is, to a certain extent, complete in itself, though even in the case of railways the rapidly increasing inter-communication between different countries makes the transition in time-reckoning on crossing the frontier more and more inconvenient. Telegraphs, however, take no account of the time kept in the countries through which they pass, and the question, as far as they are concerned, resolves itself into the selection of that system of time-reckoning which will give least trouble to those who use them.

For the time which is thus proposed for eventual adoption throughout the world, various names have been suggested. But, whether we call it Universal, Cosmic, Terrestrial, or what seems to me best of all, World Time, I think we may look forward to its adoption for many purposes of life in the near future. The question, however, arises as to the starting point for the universal or world day. Assuming that, as decided by the great majority of the delegates at Washington, it is to be based on the meridian of Greenwich, it has still to be settled whether the world day is to begin at midnight or noon of that meridian. The astronomers at Rome decided by a majority of twenty-two to eight in favor of the day commencing at Greenwich noon, that is, of making the day throughout Europe begin about mid-day. However natural it might be for a body of astronomers to propose that their own peculiar and rather inconvenient time-reckoning should be imposed on the general public, it seems safe to predict that a World Day which *commenced* in the middle of their busiest hours would not be accepted by business men. In fact, the idea on which this proposal was founded was that universal time would be used solely for the internal administration of railways and telegraphs, and that accurate local time must be rigidly adhered to for all other purposes. It was conceded, however, that persons who traveled frequently might with advantage use universal time during railway journeys. This attempt to separate the traveling from the stationary public seems to be one that is not likely to meet with success, even temporarily, and it is clear that in the future the latter class may be expected to be completely absorbed in the former. Another argument that influenced the meeting at Rome was the supposed use of the astronomical day by sailors. Now, it appears that sailors never did use the astronomical day, which begins at the noon *following* the civil midnight of that date, but the nautical day, which begins at the noon *preceding*, *i. e.*, twenty-four hours before the astronomical day of the same date, ending when the latter begins. And the nautical day itself has long been given up by English and American sailors, who now use a sort of mongrel time-reckoning, employing civil time in the log-book and for ordinary purposes, whilst, in working up the observations on which the safe navigation of the ship depends, they are obliged to change civil into astronomical reckoning, altering the date where necessary, and interpreting their A. M. and P. M. by the light of nature. It says something for the common sense of our sailors that they are able to carry out every day without mistake this operation, which is considered so troublesome by some astronomers.

In this connection I may mention that the Board of Visitors of Greenwich Observatory have almost unanimously recommended that, in accordance with the resolution of the Washington Conference, the day in the English Nautical Almanac should be arranged from the year 1891 (the earliest practicable date) to begin at Greenwich midnight (so as to agree with civil reckoning, and remove this source of confusion for sailors), and that a committee appointed by them have drawn up the details of the changes necessary to give effect to this resolution without causing inconvenience to the mercantile marine.

The advantage of making the world day coincide with the Greenwich civil day is that the change of date at the commencement of a new day falls in the hours of the night throughout Europe, Africa and Asia, and that it does not occur in the ordinary office hours (10 A. M. to 4 P. M.) in any important country except New Zealand. In the United States and Canada the change of date would occur after four in the evening, and in Australia before ten in the morning. This arrangement would thus reduce the inconvenience to a minimum, as the part of the word in which the change of date would occur about the middle of the local day is almost entirely water, while on the opposite side we have the most populous continents.

The question for the future seems to be whether it will be found more troublesome to change the hours for labor, sleep, and meals once for all in any particular place, or to be continually changing them in communications from place to place, whether by railway, telegraph, or telephone. When universal or world time is used for railways and telegraphs, its seems not unlikely that the public may find it more convenient to adopt it for all purposes. A business man who daily travels by rail, and constantly receives telegrams from all parts of the world, dated in universal time, would probably find it easier to learn once for all that local noon is represented by 17h. U. T., and midnight by 5h. (as would be the case in the Eastern States of North America), and that his office hours are 15h. to 21h. U. T., than to be continually translating the universal time used for his telegrams into local time.

If this change were to come about, the terms noon and midnight would still preserve their present meaning with reference to local time, and the position of the sun in the sky, but they would cease to be inseparably associated with 12 o'clock.

TALL CHIMNEYS.—In reference to the note on the Mechernich chimney in a recent issue, Mr. H. Stopes draws attention to two specially tall chimneys in Glasgow — Townsend's, 454 feet; Tennant's, 235 feet.

ON A NEW APPARATUS FOR MEASURING ELECTRIC CURRENTS—BY F. DE LALANDE.—This apparatus is simply formed of a bundle of soft-iron wires, placed in the interior of a metallic areometer (dydrometer), which is immersed in a test-tube filled with water, the tube being surrounded with a solenoid traversed by the current to be measured. The tube or bar of the areometer is guided through a metal eye, to prevent friction against the sides of the tube. As constructed by Mr. Carpentir, these instruments, with a displacement of 0.1 meter, show currents of 10 to 25 amperes, or a difference of potential of 100 volts. The ammeters have a resistance of 0.01 to 0.02 ohm; the voltmeters about 1,700 ohms.

IN a paper on "The Formation of Rain, Hail and Snow," recently read before the Meteorological Society by Mr. A. W. Clayden, F. G. S,. the author points out that all observations tend to show that, except under quite abnormal conditions, the temperature of the atmosphere falls as the height above sea level increases; and there seems no reason whatever for assuming that the law does not apply to that portion of the atmosphere which forms a cloud. Hence, if a drop were to be formed at or near the upper surface of a cloud, it would fall down into a region saturated with vapor at a temperature above its own. The result will be further condensation producing a larger drop; and this process will continue until it leaves the cloud. If its temperature be below the dew point of the air it falls through, condensation will continue until it reaches the ground. However, it is obvious that this subsequent gain cannot bear any very large proportion to the growth while falling through the saturated cloud, from which the conclusion follows that the size of the drop must increase with the thickness of the cloud. The author suggests that condensation begins on the upper surface of the cloud by the cooling of some of the liquid cloud particles. If this particle is cold enough it will solidify, and snow will be formed. Should it not be quite cold enough to solidify at once, owing to its minuteness, but remain still below the freezing point, hail is formed. Finally, if the temperature is not low enough for either snow or hail, rain is produced.

RANKINE'S THERMODYNAMICS.

By DE VOLSON WOOD, C.E., M.A.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

I.

THE following lecture delivered by the writer to the Senior Class in Stevens Institute of Technology, is an attempt to explain and amplify Rankine's Thermodynamics, as presented in his work on the "Steam Engine and other Prime Movers."

Rankine's Thermodynamics is not "light reading." The subject is one demanding close study, and as presented in our text-book, it is especially difficult because obscure and "sketchy"—more so, in fact, than in his original memoirs upon the subject. In print, or in correspondence, I find such expressions as "Rankine *seems* to consider;" "Rankine *appears* to make *p* a complex quantity;" "The author is too difficult because obscure;" "While Rankine, if referred to at at all, only his very words are quoted, showing that their scope is not fully grasped;"* "The more theoretical and speculative parts of the investigation are diffuse and difficult of comprehension;"† and the late lamented Clerk-Maxwell observed in regard to Rankine's second law that "its meaning is inscrutable." In view of these and other facts which we might quote, added to our own experience, no apology is needed for attempting to explain in familiar language the methods of our author. But our self-imposed task is not altogether agreeable, for we have not satisfied ourself; but our effort may stimulate, or provoke, others, as the case may be, to continue the work we have begun; to the end that the *methods* of Rankine may be more generally used.

Rankine began his investigation of this subject with the "Hypothesis of Molecular Vortices," or "Centrifugal Theory of Elasticity," which assumes *that each atom of matter consists of a nucleus or central point enveloped by an elastic atmosphere, which is retained in its position by attractive forces, and that the elasticity due to heat arises from the centrifugal force of those atmospheres, revolving or oscillating about their nuclei or central points.** From this principle he deduced all the more important equations pertaining to heat—a fact which favors the correctness of the hypothesis, but does not prove that it is realized in nature. Sir William Thomson is confident that the theory does not correctly represent nature. With this, however, we have nothing to do at present, for, as our author stated in some of his later writings, the laws of thermodynamics have become thoroughly established by experiment and experience, independent of any hypothesis in regard to molecular actions.

The first law—that of *the mutual convertibility of heat and mechanical work*—is readily understood as soon as the fact that *heat is a form of energy* is clearly apprehended. The manner of determining the relation between heat units and kinetic energy is clearly described in Stewart's work on Heat, and in other works, the result being that *the kinetic energy in a body weighing one pound falling 772 feet in a vacuum is the same as the heat energy necessary to raise one pound of water one degree Fahrenheit.* We here, for the sake of simplicity, discard considerations of variations of gravity due to latitude and elevation and the initial temperature of the water. It is unnecessary to add to the author's specific statement, except to emphasize the fact, that in all cases, whether external work be done or not, the disappearance of heat always produces an equivalent of work of some kind. Thus, in melting ice at 32° F., producing water at the same temperature, 142 units of heat disappear without

* Van Nostrand's *Engineering Magazine*, 1879, p. 337.
† Tait's Historical Sketch of Thermodynamics, p. 140.

* This principle was stated in a paper read before the Royal Society of Edinburgh, February 4, 1850, and published in the *Phil. Mag.* for December, 1851 As the author states, this hypothesis was first given by Sir Humphrey Davy, but no mathematical deductions had previously been made from it.

doing external work. This is equivalent to $142 \times 772 = 109624$ foot-pounds of work for one pound of ice. This heat is said to be *latent*, but in fact it is not heat; the heat having disappeared, become lost, destroyed, or, more properly,

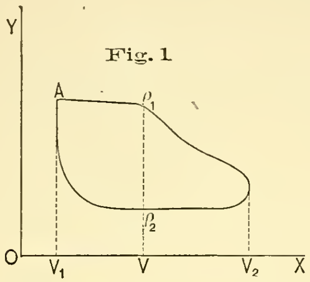


Fig. 1

that which was heat-energy has done *work* in overcoming molecular forces, changing the molecular aggregation and producing water from ice; the effect remaining in the body, maintaining the new state of aggregation until the process is reversed, when the same amount of heat is given up in returning to ice.

In the graphic representation of the first law, the author refers only to the action of an *elastic substance*, but it is desirable to know the action for an imperfectly elastic substance. As a general rule, substances expand as they become warmer, although this rule is reversed in some special cases, as, for instance, water contracts as its temperature is increased from about 32° F. to 39° F.

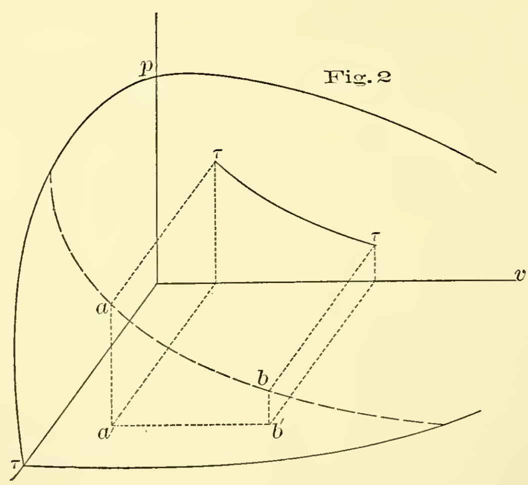


Fig. 2

It is assumed that, whatever be the nature of the substance, whether a perfect or imperfect gas, or semi-liquid, that the movement of the piston in an engine or in an indicator is due entirely to the effect of heat; and that the closed area, representing external work, has its exact equivalent in heat units. Or, in other words, the heat changed into external work is represented by the closed figure, but is no indication of the heat expended in doing internal work, such as overcoming molecular attraction, viscosity or any other force known or unknown. The indicator diagram becomes a measure of the heat transformed into work, regardless of the nature of the substance doing the work.

The thermal lines represented on page 302 of our text, are of great value in representing to the eye the relations existing between the pressure and volume of a substance when subjected to certain conditions. We find in regard to conditions dependent upon temperature, that they are also dependent upon the specific volume of the substance and the pressure to which it is subjected, or, in other words, is a function of three variables; and we may write

$$\varphi(\tau, v, p) = o,$$

or $p = f(v\tau)$, $v = f'(\tau, p)$, $\tau = f''(v, p)$;

and these may be considered as the equations to a surface in space, called a thermodynamic surface. Let the axis of volumes be a horizontal line, and of pressures a vertical one, both in the plane of the paper, and the axis of temperatures perpendicular to the former. If τ be constant, then

$$p=f(v)$$

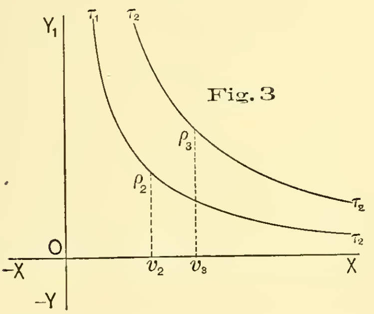
will be the projection of on the plane pv of the curve of intersection of a plane parallel to pv with the thermodynamic surface: and this curve is called *isothermal.* Similarly, if τ be eliminated, giving a relation between p and v, the resulting thermal line is called *adiabatic*, or, according to Clausius, *isentropic.*

The algebraic condition for a perfect gas is (page 229 of the text)

$$pv=\frac{p_0v_0}{\tau_0}\tau=\mathrm{R}\tau \qquad (a)$$

but if the temperature be constant, let τ_1 be that temperature, then

$$pv=\mathrm{R}\tau_1 \qquad (b)$$



will be the equation of isothermal lines, and is the equation of an equilateral hyperbola referred to its asymptotes, p and v being variables.

Let ox and oy be rectangular axes, v being measured on ox and p parallel to oy. In equation (b) let τ be any assumed value, say 500° F., then will the equation for air become

$$pv=53.15\times500=26575;$$

but for convenience in using a scale, we will take

$$pv=4,$$

in which case the true values of p and v will be 26575÷4 times the values given by the figure. If $v=1, p=4$; if $v=2, p=2$; if $v=4, p=1$, &c., by means of which, and other values the curve $\tau_1\tau_1$, Fig. 3, may be constructed to any required degree of accuracy. Similarly, if

$$pv=9,$$

a curve represented by $\tau_2\tau_2$ may be constructed. If v be negative, p will also be negative, and the curve will be constructed on the axes $-x$ and $-y$. Both the axes, ox and oy, are asymptotic to all isothermal curves.

The formula for an imperfect gas is empirical, but taking our author's equation for carbonic acid gas, page 229, we have

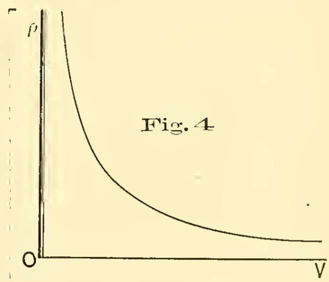
$$\frac{pv}{17264}=\frac{\tau}{\tau_0}-\frac{3.42}{\tau}\times\frac{8.15725}{v} \qquad (c)$$

Let $\tau=\tau_0=493.2$; then

$$pv=17264-\frac{977}{v}, \text{ nearly.}$$

$$\therefore\ v=\frac{8632}{p}\left\{1\pm\sqrt{1-\frac{977}{(8632)^2}p}\right\}$$

This gives two values for v for every value of p, but for a large range of values



of p, say from 0 to more than 50,000, the radical part will be but little less than unity, and hence one value of the parenthetical part will be but little less than two, and the other only a little above zero. The former values are represented by the heavy curve in Fig. 4, which differs but little from that of a perfect gas, and the latter by the dotted line. If the radical part be neglected the equation would become

$$v=\frac{8632}{p},$$

which is the exact law for a perfect gas at the temperature of melting ice (since it has been assumed above that $\tau=\tau_0$). If $p=o$, $v=\infty$. The value of v becomes imaginary in equation (c) for $p>\frac{(8632)^2}{977}$, or $p>76{,}300$. It is not, however, safe to rely upon extreme values in an empirical equation. Equation (c) shows that the pressure p will be less for a given value of v, τ being constant, than if the gas were perfect.

In order to construct accurately adiabatic (or isentropic) curves, it will be necessary to anticipate their equations, which we do in order to obtain a more definite idea of their form. The exact equations of these curves are known only for perfect gases, one form of which is given on page 249 of our text, and is

$$p \propto D^{\gamma}, \text{ or } pv^{\gamma} = \text{constant}, \qquad (d)$$

where $D = 1 \div v$; and this combined with equation (a) will give the relation between p and τ, or v and τ, as given on page 319, which relations are

$$\frac{\tau}{\tau_1} = \left(\frac{v_1}{v}\right)^{\gamma-1}; \quad \frac{p}{p_1} = \left(\frac{\tau}{\tau_1}\right)^{\frac{\gamma}{\gamma-1}}; \quad \frac{p}{p_1}\left(\frac{v_1}{v}\right)^{\gamma}; \qquad (e)$$

in which $\gamma = 1.408$ for a perfect gas.

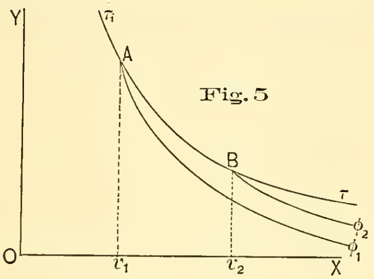


Fig. 5

If one of these curves be made to pass through the point $p_1 = 4, v_1 = 1$, and making $\gamma = 1.4$, we have from the third of equations (e),

$$pv^{\gamma} = 4.1^{\gamma} = 4,$$

by means of which the curve $A\varphi_1$ has been constructed. If another of these curves be made to pass through $p_1 = 2$, $v_1 = 2$, we will have

$$pv^{\gamma} = 2 \times 2^{1.4}$$

by means of which $B\varphi_2$ has been constructed. The points A and B have, intentionally, been taken on the isothermal

$$pv = 4 = p_1 v_1,$$

but the curves $\varphi_1 A$ and $\varphi_2 B$ may extend above $A\tau_1$.

The isentropic (or adiabatic) relations between p and τ may be shown graphically by using the rectangular axes $o\tau$ and op, the values of τ being laid off on the former and those of p parallel to the latter. If $\tau_1 = 1$ when $p_1 = 4$, we have from the second of (e),

$$p = 4\, \tau^{3.45}$$

by means of which the curve oA has been constructed.

It is nearly a cubic parabola having Op for its axis.

Similarly, for the graphic representation for the relation between τ and v, we use Ov for the axis of the v's as before, and Oτ vertical, then if the curve be made to pass through the point $v_1 = 1$ and $\tau_1 = 4$, we have, from the first of equations (e),

$$\tau v^{0.408} = 4,$$

by means of which a curve τv may be constructed.

The first and third of equations (e) are asymptotic to their respective axes, for if $v = o$, $p = \infty$ and $\tau = \infty$; and if $v = \infty$,

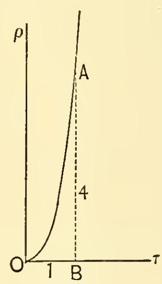


Fig. 6

$p = o$ and $\tau = o$. These adiabatics are for perfect gases, but the general characteristics given by our author on page 302 are applicable to imperfect gases. The adiabatics for imperfect gases always slope downward more rapidly than the isothermals.

It is advisable to become familiar with the principles involved in these curves before proceeding further. For this purpose conceive that a perfect gas in the lower part of a cylindrical vessel is supporting a frictionless but perfectly fitting piston; and that the sides of the vessel including the piston and base, are perfect non-conductors of heat. If now the piston be forced downward, three things will happen: 1°, the pressure of the gas against the piston will be increased; 2°, the volume of the gas will be diminished; and 3°, the temperature of the gas will be increased. These effects are all illustrated by the line $A\varphi_1$,

Fig. 5; for in passing from a given volume v_2 to a smaller one v_1 the ordinates of the curve increase, becoming v_1A at v_1, and the temperature also increases for the curve approaches and finally intersects the isothermal line ABτ_1.

Now, reversing the operation by pulling the piston upward, or outward, and it will be found that the pressure of the gas against the piston is diminished, the volume increased and the temperature diminished. These results are also shown by the line Aφ_1, Fig. 5, passing from A towards φ_1. It is well to notice that, under the conditions imposed, if *one* of the quantities p, v, τ, be fixed, the other two also become fixed. Thus, if the temperature be maintained constant, there being no transmission of heat, it will be impossible to move the piston, and hence p and v must be unchangeable; not because it is physically impossible to move the piston, but because the piston cannot be moved without raising or lowering the temperature. Similarly, if the condition be that p shall be constant, v and τ become fixed. Here, then, is a case in which the three quantities p, v, τ, are not only mutually dependent, but are so related that a given change of one necessitates a definite change in both the others; and if one be fixed the others are as fixed as if the substance were a perfect solid. Continuing the expansion by pulling the piston outward, the pressure and temperature will continually fall, as shown by the curve Aφ_1, Fig. 5, and the first and third of equations (e) show that for $v=\infty$, the pressure and absolute temperature both become zero. The entire work done by the gas upon a piston during this indefinite expansion was the *intrinsic* energy of the gas at the beginning of the expansion. If, however, the gas be imperfect, the entire energy in the gas will equal the entire heat absorbed by the substance, less the internal work done upon the substance in raising it from a zero pressure to the final pressure; and is also equal to the energy which it is capable of imparting to a piston during an indefinite expansion without transmission of heat, plus the energy expended in overcoming its own molecular forces during such expansion. The *intrinsic* energy is the energy which the gas is capable of imparting to a piston without transmission of heat during an indefinitely extended expansion. In perfect gases the intrinsic energy is the entire energy, but in imperfect gases the intrinsic energy is less than the entire energy by an amount equal to the energy absorbed by the gas during the indefinite expansion.

If the "total actual heat," or simply the "actual heat" were the result of the linear motions of the molecules, then for a mass m the heat would be $\frac{1}{2}mv^2$, where v^2 is the mean of the squares of the actual velocities of the molecules of the body. To test this hypothesis, take the case of air, the specific heat of which at constant volume is 0.169, that of water being unity; and at the melting point of ice, 32° F.=493°.2 F. absolute, we have for the energy of one pound

$$k\tau=0.169\times772\times493^\circ.2=64264 \text{ foot-pounds,} \quad (f)$$

then $$\tfrac{1}{2}\cdot\tfrac{1}{32.2}.v^2=64264;$$

$$\therefore\ v=2033 \text{ feet per second.}$$

But it is known that the velocity of the molecules of air producing a pressure of of 14.7 pounds per square inch is less than 1,600 feet per second. In the present volume of this Magazine, page 51, equation (3), if $x=3$ (the value commonly used), $e=14.7\times144$, $\delta=w\div g$, and $w=0.08$ of a pound, then $v=1560$ feet per second; or somewhat more than $\frac{3}{4}$ the former value. The molecules, therefore, must have some motion other than rectilinear, either wholly or partly, to produce the phenomenon of heat.

Next, suppose that the cylinder admits of the passage of heat through its walls. If now the piston be gradually forced inward, the heat generated will escape through the sides of the vessel and the temperature may be made to remain constant. In this way work may be done upon the fluid at constant temperature, while the volume and pressure both vary according to the law given in equation (b), the volume decreasing from Ov_2 to Ov_1, while the pressure increases from v_2B to v_1A. Reversing the operation by permitting the piston to move outward, the volume will be increased, the pressure decreased, and to maintain a constant temperature heat must be supplied from an external source. According to the first law, the entire heat supplied from an external source must equal *the entire* *work done*, when the temperature continues constant, and hence for a perfect gas the *external* work done will equal the heat so supplied. To show this let AB be an isothermal line, the area v_1ABv_2 will represent the external work done by the gas in expanding from Ov_1 to Ov_2; and the shaded area MbBN between the adiabatics AbM and BcN indefinitely extended, added to the area ABbA, will represent the heat supplied in doing that work. We first show that the shaded part v_1Abv_2 equals the shaded part $MbBN$ indefinitely extended.

Let $$pv=a \qquad (g)$$
be the equation of AB,

that of AbM,
$$pv^{\gamma}=b \qquad (h)$$
and that of BcN
$$pv^{\gamma}=c \qquad (i)$$

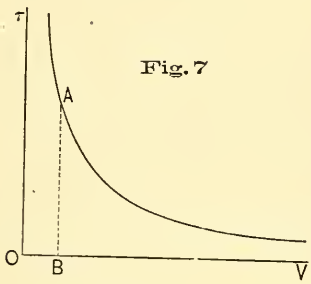


Fig. 7

Assuming that the co-ordinates of A are known and represented by p_1 and v_1, we have $p_1v_1=a$, and since AM passes through this point its equation must satisfy the co-ordinates of the point, or $p_1v_1^{\gamma}=b$; hence by elimination we find

$$b=av_1^{\gamma-1} \text{ or } =a^{\gamma}p_1^{1-\gamma}$$

Similarly, the co-ordinates of B being p_2 and v_2, we find

$$c=av_2^{\gamma-1}=a^{\gamma}p_2^{1-\gamma}$$

and the equations to the adiabatics become completely known.

The area of v_1Abv_2, using equation (h), is

$$\int_{v_1}^{v_2} pdv=\int_{v_1}^{v_2} bv^{-\gamma}dv=\frac{b}{1-\gamma}$$

$$(v_2^{1-\gamma}-v_1^{1-\gamma})=\frac{a}{1-\gamma}(v_1^{\gamma-1}v_2^{1-\gamma}-1)$$

Let $p_c=vc, p_d=vd$, then from equations (h) and (i)

$$cd=p_c-p_d=(c-b)v^{-\gamma}$$

and the entire extended area will be

$$\int_{v_2}^{\infty}(c-b)v^{-\gamma}dv=-\frac{c-b}{1-\gamma}v_2^{1-\gamma}$$

$$=\frac{a}{1-\gamma}(v_1^{\gamma-1}v_2^{1-\gamma}-1) \qquad (j)$$

which is the same as that above. Hence, adding AbB to both gives $ABv_2v_1 = MbABN$, the latter being indefinitely extended.

If the volume be constant the pressure and temperature may vary, and generally in the same sense; that is, if the temperature be increased the pressure will also be increased, and the thermal line on the plane pOv will be a right line parallel to Op. Similarly, if the pressure be constant, the volume and temperature may vary in the same or opposite

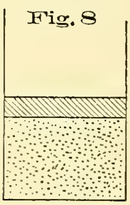
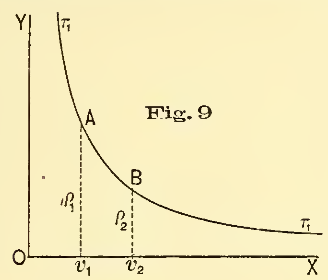


Fig. 8

senses; but in either case the thermal line on the plane pOv will be a right line parallel to Ov. The thermal lines, in these cases, on the planes $pO\tau$ and $vO\tau$ will depend upon the algebraic relations between p, τ and v; and will be right lines for perfect gases, and curved for imperfect gases. When heat is absorbed by the fluid while external work is being done, the termal line during the performance of work may be made to assume almost any form. In Fig. 13, if the initial position of the piston be at v_1, by forcing it towards O, or allowing it to move outwards towards v_2, while the absorption of heat causes the pressure to rise, the thermal line ACB may be described. During the movement from A to C work will be done by the piston upon the fluid, the volume being diminished while the pressure and temperature were increased. The total heat supplied to a perfect gas from an external source during the operation ACB is represented by the indefinitely prolonged area MACBN, where AM and BN are adiabatics.

In Fig. 14 let Bv_2 be the pressure exerted by a gas when its volume is Ov_2, and BN be an adiabatic passing through B, then if the *gas be perfect*, its entire energy will be represented by the indefinitely extended area Xv_2BM, and, conversely, the area Xv_2BN will represent the heat imparted to the fluid, while the pressure is raised from zero to v_2B, the volume being constant; but if the *gas be imperfect*, this area will not represent the heat received by the substance during the operation v_2B, since some *work* will have been expended in charging molecular conditions. Conceive a pound of this gas at the volume represented by Ov_2, and called "volume v_2" be destitute of of heat, and hence also of pressure. Let this volume remain fixed, as if it were in

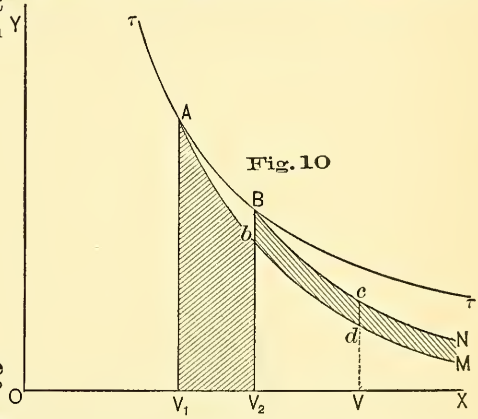


a sphere, or cylinder, of unchangeable size, while the gas is heated from 0° to temperature T; then will the pressure rise from 0 to v_2b, Fig. 14. If the gas be perfect and bn an adiabatic curve, the indefinitely extended area nbv_2x will *represent* the heat supplied, the actual heat being also dependent upon the specific heat of the gas, as will appear further on. If the gas be imperfect, the heat absorbed at the same temperature, τ, will exceed the area nbv_2x by an area representing the internal work done, which is shown in Fig. 14 by the narrow shaded strip above the isothermal τ passing through b and conceived to be indefinitely extended to the right. But the pressure in the vessel containing the imperfect gas will be less than v_2b, and may be represented by v_2B; in which case the adiabatic will pass through B.

As an example of the fact that the pressure of an imperfect gas at temperature τ is less than for a perfect one at the same temperature and volume, we again take the case of carbonic acid gas, equation (c), which may be written in the general form

$$p = R\frac{\tau}{v} - \frac{a}{\tau v^2} \qquad (k)$$

where $R = \frac{p_0 v_0}{\tau_0}$ and $a = 3.42 \times 8.15725 \times 17264 \div 493.2$. The first term of the second member is the same as if the gas were perfect, and since a and τ are positive, the second term will be negative, making the pressure p less for the imperfect gas. Next, conceive this pound of gas at the temperature τ and pressure v_2B to be continued in a cylinder having a free, frictionless piston, and that the piston moves outward without communication of heat between the contained gas



and external bodies, then will the pressures for corresponding volumes be the ordinates to the adiabatic BN, and a portion of the heat of the gas will be consumed in doing work upon itself, which may be represented by an area above BN, as NBbn for instance.

The indefinitely extended area NBv_2X represents the intrinsic energy of the gas; and if

$$k\tau = \text{area } nbv_2X$$

$$S = nbBN$$

$$q = \text{the intrinsic energy,}$$

then $$q = k\tau - S.$$

During the expansion along an adiabatic work is done, but no heat is supplied. Now let heat be supplied while external work is being done. Let A represent the initial condition as to pressure and volume of an imperfect gas;

then will the isothermal corresponding to this pressure pass through some higher point as a, and the area $ma\ v_1 X$ indefinitely extended, will represent the total energy in the gas due to the temperature τa or pressure $v_1 A$. Now, let the gas absorb heat, raising the temperature and pressure while the piston moves outward from Ov_1 to Ov_2, doing both external and internal work, the pressure increasing from $v_1 A$ to $v_2 B$, the isothermal rising from some point a to another b. The internal work will depend upon the two elements—increase of temperature and expansion, and these may be considered separately, and hence will depend upon the initial and final states only. The internal work is represented by $AabB$, but the amount of heat required to perform this work is, as yet, unknown. Now, let the gas expand without communication of heat—or, as we

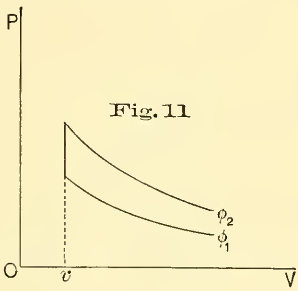


Fig. 11

say, expand adiabatically along the adiabatic BN—to vf, it will do an amount of external work represented by $v_2 Bfv$, and of internal work represented by $fBbh$, and since there is no communication of heat the latter must be done at the expense of the heat which was in the body at the state B. At f let the heat be abstracted until the pressure falls from f to g. We do not as yet know how much heat must be abstracted to accomplish this result, since internal work will be performed. If internal work is done when the temperature is increased, heat will be imparted to the substance from the substance itself when the temperature is decreased, so that gi will exceed fh. In this case we do not measure the temperature, and much less the heat, but the *pressures* are reduced from f on the adiabatic BN vertically down to g on the adiabatic AM. It is apparent that the further gf is removed to the right the less will be its length; or, in other words, the less will be the pressures between the adiabatics, and will vanish when removed indefinitely. The lines bn and am also approach the adiabatics as they are extended, and all these lines, bn, BN, am, AM, are asymptotic to OX. Now, compress the substance along the adiabatic gA bringing it to the condition A. During the last operation heat will be given out by the substance on account of the compression, but work will be done in the substance on account of the increase of temperature. We now have from the figure—the right hand areas being indefinitely extended,

$$nbv_2X + bv_2v_1a - nav_1X = nbam.$$

But $nbam$ represents the entire heat in foot-pounds absorbed above its initial condition. Let H_a be the entire heat in the state $A = mav_1x$, and H_b the heat in the state $B = nbv_2x$; then we have, after

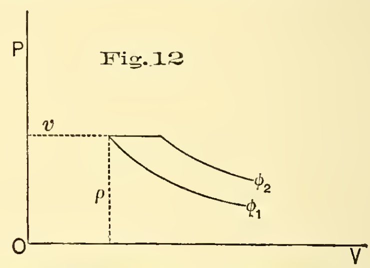


Fig. 12

separating the former equation into other elements,

$$H_b - H_a = nbBN + NBv_2x + baAB + Bv_2v_1A - maAM - MAv_1X. \quad (l)$$

But the work done on any substance in a cycle—that is, the work done on any substance in producing changes as to pressure, volume and temperature, but finally bringing it back to its original condition—must be zero. Hence,

$$nbBN + baAB - maAM = o.$$

Let $$baAB = S$$

$$nbBN = S_b$$

$$maAM = S_a$$

then, the preceding equation gives

$$S = -S_b + S_a \quad (m)$$

and equation (l) becomes

$$H_b - H_a = NBv_2X + Bv_2v_1A - MAv_1X = MABN$$

or,

The mechanical equivalent of the heat absorbed (*or given out*) *by a substance in passing from state* A *to state* B, *is represented by the area included between the curve* AB *and two adiabatics through* A *and* B, *and indefinitely prolonged in the direction representing increase of volume.*

This is the THEOREM on page 303 of the text.

Also, let

$$v_1 AB v_2 = \int p dv$$

and equation (l) becomes

$$H_b - H_a = NBv_2X + \int pdv - MAv_1X$$

which is the equivalent of equation (2), page 305 of the text.

But to put it more nearly in the *form* of that equation, let

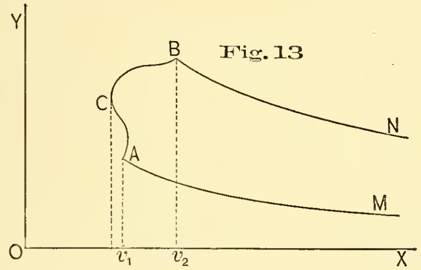


Fig. 13

$Q_b = nbv_2X$ = the total heat in the substance in the state B,

$$Q_a = mav_1X,$$

then equation (l) becomes

$$H_b - H_a = Q_b + S + \int pdv - Q_a,$$

which, combined with equation (m), gives

$$H_b - H_a - \int pdv = Q_b - Q_a - S_b + S_a \quad (n)$$

This is equation (2), page 305, except that the signs of S_b and S_a are the reverse of these here given, but this is not vital, since the author in this place has simply assigned the *form* of the expression without determining the signs of these terms. The correct sign, however, is prefixed by the author on page 313 of the text. Those who can follow the steps of the author and be convinced of the correctness of the reasoning when applied to imperfect fluids, do not need the detailed work here given.

The author now finds it necessary to introduce another principle in order to find a measure of work, including the internal as well as the external, and this is involved in his SECOND LAW. It may be stated in different forms, but the idea involved may be thus analyzed:

1°. Energy, like any other quantity, may be divided into an indefinite number of indefinitely small equal parts.

2°. Any one of the equal parts will do the same amount of work, and in doing work each does its proportionate share of the entire work.

3°. In a homogeneous substance, the total work done is the sum of all its parts.

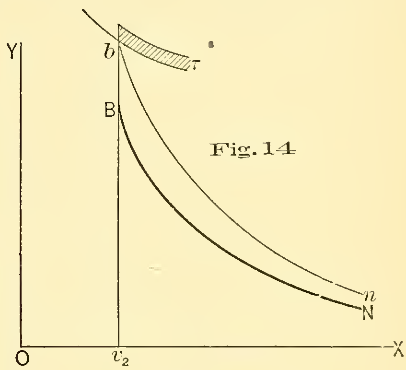


Fig. 14

The author has such an abstract way of stating some of his general propositions that we would often be in doubt how to apply them had he not given samples. In this case he has given us his "symbolic expression" of his law, and it amounts substantially to this:

To find the rate of doing work, both external and internal, per unit of heat.

But this is anticipating, somewhat, the further development of the subject.

The author restricts his definition to the case of a homogeneous and uniformly hot body, and this condition may be complied with in the analysis by considering, at first, only an infinitesimal portion of the substance, and then extending it to so much of the finite portion as is included within the conditions. The author, on page 308 of our text, states that it is applicable to heterogeneous masses. The term "hot" applies to so much of the heat which has been absorbed by a body as is retained in a condition for doing work, the heat which has already done internal work not being considered. When applied to perfect gases, in which increments of pressure are equal for equal increments of temperature at any and all points of the scale of temperature, the law appears to be sufficiently evident, and is, at least, free from difficulty; but not so when applied to imperfect gases. Rankine's statement of the second law is *quantitative*, and in this respect is superior, as a working basis, to the principle stated by Clausius and Thomson. Clausius says "heat cannot without compensation pass from a colder to a hotter body," which is a *qualitative* statement and destitute of a basis for measuring the quantity which may pass from one body to another.

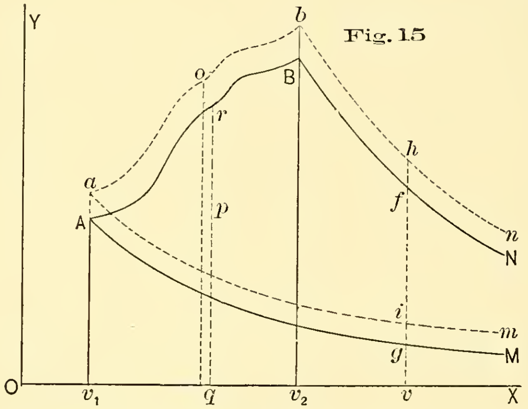


Fig. 15

Rankine recognizes this principle of Clausius as a property of heat (see page 224 of our text). Thomson states his principle thus: it is impossible to work a heat engine at a lower temperature than that of the lowest temperature of surrounding objects; but this rather gives a limit than a basis for measurement.

In illustrating this law we first make use of a rigid body in motion, an example suggested by our author on page 306. Let M be the mass of the body having a velocity v, doing work by sliding along a rough horizontal plane; and, in order to simplify the problem, assume that the only work done is in overcoming friction (no internal work), and that the friction is uniform (similar to that of a homogeneous and uniformly hot body). The kinetic energy of the body will be $\frac{1}{2}Mv^2$, which we assume is all consumed in the distance AB. The work done will be the resistance per unit of length into the distance AB, which call U; then

$$U = \tfrac{1}{2}Mv^2, \text{ also} = Q.$$

Now, let the entire mass undergo an indefinitely small change of velocity, during which it moves over the indefinitely small space Aa, then

$$dU = \tfrac{1}{2}Md(v^2) = Mvdv = dQ.$$

Next, let the body be divided into an indefinite number of indefinitely small parts, each being dM; the energy of each one of these parts will move the entire body over an indefinitely small, but proportional part, of Aa, and we have

$$d(dU) = dM \,.\, d(\tfrac{1}{2}v^2),$$

and the rate of doing one of these small parts of work per *unit* of energy will be

$$\frac{d\,(d\,U)}{d\,Q}$$

and hence for the total energy the work done will be Q times as much, or

$$Q\frac{d\,(d\,U)}{dQ} \qquad (o)$$

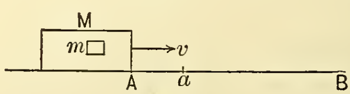


Fig. 16

It is true that this analysis, followed out, will lead to an identity, as it ought, since all the energy is here transformed into external work, and in this respect is similar to the case of work done by a perfect gas. This example may be useful in fixing our ideas since it deals with terms and quantities with which we are already familiar. We notice that du is due to an infinitesimal change of the mass of the entire body and $d(du)$ to an infinitesimal part of the body.

The notation used by the author, viz.:

$$\delta Q \cdot \frac{d}{dQ} dU$$

is not common in elementary works on the calculus, but is frequently used in higher works. The d above the bar extends its power of differentiation to all of the quantity following the bar, so that it is here equivalent to

$$\delta Q \cdot \frac{d(dU)}{dQ} = \delta Q \cdot \frac{d^2U}{dQ}$$

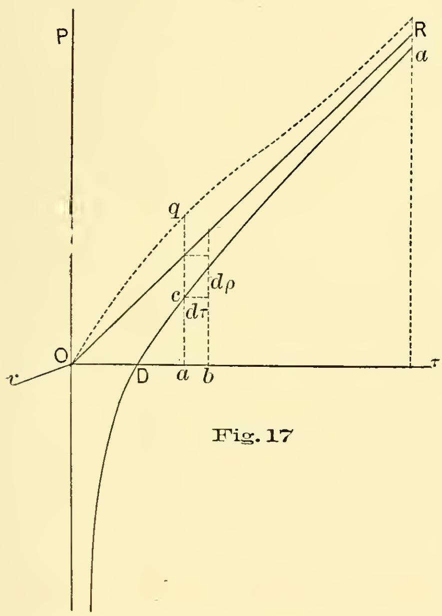


Fig. 17

When the external work is not a function of x and y, Clausius makes a distinction between

$$\frac{d}{dy}\left(\frac{du}{dx}\right) \text{ and } \frac{d^2u}{dydx},$$

but we shall have no occasion to make even this distinction; hence, we may, if we choose, use d^2U for $d(dU)$, as our author did in some of his original papers, The author, in his Memoirs, also wrote dQ in place of the δQ of our text, and here is no advantage in the latter over he former; although both are correct, as we shall soon see, so that the expression may be written

$$dQ \frac{d^2U}{dQ},$$

which, as it stands, is equivalent to d^2U, still the *form* is a convenient one for use.

If p be the normal pressure against the interior of the vessel, and the vessel be enlarged an elementary amount, dv, then will an element of the external work be

$$dU = pdv,$$

and, considering v as the independent variable, we have, by differentiating again

$$d\,(dU) = dpdv,$$

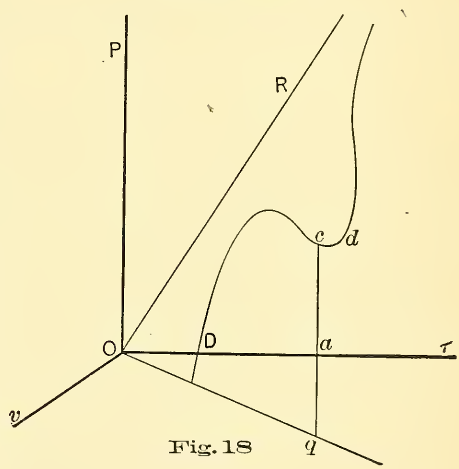


Fig. 18

where the parenthesis might be retained to indicate that the second differential is not made in reference to the same variable as the first, but this is unusual and unnecessary. Substituting the last equation in the general one, we have

$$dQ \cdot \frac{dp}{dQ} dv,$$

and this is a more convenient form for discussion than expression (o), and is identical with the form used by the author in some of his original papers. In this case pdv is an element of work due to a small variation in the entire heat, while $dpdv$ is an element of work due to a small variation in an elementary amount of heat.

This being the work done by the heat dQ, then since by *the second law* every

dQ from zero to Q does the same amount of work, the elementary work done by the total heat Q is

$$Q \cdot \frac{dp}{dQ} dv.$$

Since Q is the sensible (or *actual* heat) only, and the *absolute* temperature, τ, is made proportional to the quantity of sensible heat, we have

$$Q : \tau : : dQ : d\tau,$$

or $$\frac{Q}{dQ} = \frac{\tau}{d\tau},$$

and the former expression becomes

$$\tau \frac{dp}{d\tau} dv$$

which form is given by our author in the *Philosophical Magazine*, 1854, (2), page 357. These forms are all equivalent, and we may write

$$Q \frac{d}{dQ} dU = Q \frac{d^2U}{dQ} = \tau \frac{d}{d\tau} dU = \tau \frac{dp}{d\tau} dv,$$

the last of which is the most convenient for discussion, since in it we may consider one element at a time, whereas, if U be used, we have to consider a complex quantity involving force, v, and space, v.

Returning now to page 306 of the text, we find that the author says, "It is required to find how much of this work is performed by the disappearance of heat."

If this expression be correct and exact, it is to us unintelligible; or we do not understand the "scope" of the words. If we had no means of determining the author's meaning except our text, we would expunge the words "of this" so that the sentence would read, "how much work is performed by the disappearance of heat," for then it would be in exact harmony with the text. Only four lines below the above sentence, the author says, "will cause to be performed the quantity of work," and only two lines further the author says, "the quantity of work performed by the disappearance of heat will be," which is precisely what the original expression becomes when the words "of this" are canceled; and again on page 310, "then the work performed by the disappearance of heat is," and all these expressions refer to the same thing.

In no other place in the text is there any intimation that all of the work performed is not done by the disappearance of heat, and both the language and analysis authorize us to cancel these words, and we may safely do so. On the other hand, we are slow to admit that they were inadvertently inserted, and we find, upon consulting his original paper, that he there uses the same expression. Some have suggested that Rankine had in mind the fact that work was done by this substance on account of some other agency than heat, such, for instance, as electricity, or magnetism, or some other agent unknown. To us it seems impossible to separate the effects of unknown agents by the process of logic which he uses. But we are not left in doubt on this point. In his Miscellaneous Scientific Papers, page 221, he says: "Let a homogeneous substance possess a quantity Q of a particular kind of actual energy, uniformly distributed, and let it be required to determine the amount of the effect arising from the actual energy, which tends to perform a particular kind of work by the variation of a particular passive accident." It is only a "particular kind of actual energy" that is considered in producing a particular kind of work.

Again, on page 311, it says "part of pdv is produced by molecular attractions and repulsions . . . it is not the direct effect of heat, although they may be modified by heat. . . . It is required to determine how much of pdv is the effect of heat." One would infer from these statements that only a part of pdv is produced by heat, and yet in the analysis following the remarks, it appears that the heat which produces the external work pdv also does internal work in addition. If the expression "how much of this," means "how many times this," it becomes consistent. It is possible that the author, at that time, entertained the view, that there were molecular repulsions independent of heat, as was supposed to be shown by the fact that the zero of the gas thermometer did not coincide with the zero of the absolute scale.

From the data at his command he found that the zero of the absolute scale was three or four degrees below that of the zero of an air thermometer graduated according to Fahreneit scale. (Professional Papers). But the experiments of Regnault showed that the two zeros practically coincide. Whatever be the idea originally contained in the expression with the words, "of this," retained, it is certain that, with our present knowledge of the subject, they may be expunged.

Returning now to the consideration of the subject, the proposition is, let unity of weight of a homogeneous substance, possessing the actual heat Q, or absolute temperature τ, undergo an indefinitely small change (of volume, for instance) so as to produce the indefinitely small amount of work $d\text{U}=pdv$; it is required to find how much work (both external and internal) is done by the disappearance of heat. Let the temperature be maintained constant by heat supplied to the substance from an external source while the volume is enlarged by the amount dv, then will the heat disappearing equal the amount supplied.

This is the author's mode of treatment. On page 310 of the text he says, "In determining that function . . . it is first to be investigated as if the temperature were constant, and then the law of its variation with absolute temperature be found;" and in his paper on the Mechanical Action of Heat: "and let us investigate how much heat becomes latent or is converted into mechanical power, during this process (which consists in expanding an amount dv); the thermometric heat *being maintained constant* so that the heat which disappears must be supplied from an external source." (Professional Papers, page 311).

Considering the volume constant, the rate of increase of the pressure per degree of temperature at the temperature τ will be according to the calculus,

$$1^\circ \frac{dp}{d\tau},$$

and since each of the $d\tau$'s in 1° will, according to the Second Law, produce the same increment of pressure, we have for the pressure produced by $d\tau$

$$d\tau \frac{dp}{d\tau}, \qquad (m)$$

which is quite evident since the expression is equivalent to dp; and similarly for an element $\delta\tau$, which may be different from $d\tau$, we have for the same reason,

$$\delta\tau \frac{dp}{d\tau},$$

but which is not equivalent to dp, and for the same reason, for all the elements in τ, we have the pressure

$$\tau \frac{dp}{d\tau},$$

which, for an enlargement dv, will perform the work

$$\tau \frac{dp}{d\tau} dv,$$

and since the temperature has been maintained constant, this work expressed in thermal units will give the heat which disappeared. To test this result, first, take the case of a perfect gas, for which we have

$$\frac{dp}{d\tau}=\frac{p}{\tau},$$

which, substituted above, gives

$$\tau \cdot \frac{p}{\tau} dv=pdv,$$

the well known expression for an element of work.

If the substance be an imperfect gas then is $\frac{dp}{d\tau}$ generally greater for any finite value of τ than it would be if the substance were a perfect gas at the same temperature. First, take carbonic acid gas, for which we have equation (c), or

$$pv=\text{R}\tau-\frac{a}{\tau v},$$

Differentiating, regarding v as constant, we have

$$\tau\left(\frac{dp}{d\tau}\right)_v=\text{R}\frac{\tau}{v}+\frac{a}{\tau v^2}=p+\frac{2\,a}{\tau v^2}$$

If the substance were a perfect gas we would have $\tau\frac{dp}{d\tau}=p$, but in this case the result is greater than for a perfect gas by the amount of the second term, or $\frac{2\,a}{\tau v^2}$. The same general result would follow from our author's more general equation of an imperfect gas, page 229, which is

$$\frac{pv}{p_0 v_0}=\frac{\tau}{\tau_0}-\text{A}_0-\frac{\text{A}_1}{\tau}-\frac{\text{A}_2}{\tau^2}-\&\text{c}.$$

But we will arrive at the same general result from more general reasoning. Thus, experience shows that the higher the temperature the more gaseous do all known substances become. In some cases the temperature must be very high before the solid becomes a liquid, and very much higher before it will vaporize; still the fluidity continues to increase with increase of temperature, and we assume that if the temperature could be sufficiently high the substance would ultimately be reduced to a gaseous condition. There being internal work, the pressures due to heat at low temperatures will be lower than if the heat had not that work to do, in other words, less than if the substance were a perfect gas; hence, the pressure starts lower at a given low temperature than if it were a perfect gas, but reaches the same value at very high temperatures. Between these low and high temperatures, therefore, the range of pressures is greater for the imperfect gas than for the perfect; and hence the increments of pressure in the latter case must exceed those in the former. These principles may be illustrated by means of a diagram. Let Oτ be the axis of temperatures, and Op, of pressures. For a perfect gas we have, equation (a),

$$p=\frac{\mathrm{R}}{v}\tau$$

which may be represented by a right line OR, though the origin, O, v being constant

For an imperfect gas we conceive that it requires some heat to induce any pressure, so that for $p=o$, we have a finite value for τ giving a point D and that additions of heat causes a rise in pressure giving the line Da which approaches more and more nearly to OR as the temperature increases. In the case of carbonic acid gas, making $p=o$, we find

$$\tau=\sqrt{\frac{b}{av}},$$

which equals oD; but empirical equations cannot be trusted to such an extreme.

Divide $o\tau$ into any number of small equal parts, each equal $d\tau$, and erect ordinates to OR intersecting Da; then will each dp for the curve Da exceed that for the line oR. The expression

$$\frac{dp}{d\tau}$$

is, in the language of the calculus, a rate, which, being written out fully, is in this case—*the pressure which would be produced by a unit of temperature provided the rate remained uniform as at the beginning of the pressure.* This may be written

$$1^\circ\frac{dp}{d\tau},$$

which is the increase of pressure for 1° at the rate

$$\frac{dp}{d\tau},$$

and, as before stated, we deduce the expressions

$$d\tau\frac{dp}{d\tau},\quad \delta\tau\frac{dp}{d\tau},\quad \tau\frac{dp}{d\tau}.$$

Now, let the volume vary by an amount dv, while the temperature τ is maintained constant by a supply of heat from an external source, then will

$$d\mathrm{W}=\tau\frac{dp}{d\tau}dv=\tau\frac{d(d\mathrm{U})}{d\tau}$$

be an element of work done, both external and internal when τ is the absolute temperature and p the external pressure. This expression is fundamental, lying as it does at the very foundation of our author's analysis; we, therefore, dwell upon it. At least, one writer of good repute failed to get a correct conception of this expression, for he says "Rankine, however, seems to apply this law to determine the rate at which external work will be performed,"* and having this misunderstanding he attempted to enlarge the Second Law so as to make it include internal work; but Rankine left no doubt as to his meaning on this point, for in an article in *The Engineer* of June 28, 1867, he says: "This law is capable of being stated in a variety of forms, expressed in different words, although virtually equivalent to each other. The most convenient form for the present purpose appears to be the following:

To find the whole work, internal and external, multiply the absolute temperature at which the change of dimensions takes place, by the rate per degree at which external work is varied by a small variation of the temperature.

Had the author expressed himself as clearly in our text as in the above quota-

* *Van Nostrand's Magazine*, 1879, p. 337.

tion, students would have been saved much perplexity. In this statement *the rate* is between work and temperature, and in this form agrees with the text, and may be written:

$$\frac{d\,(du)}{d\tau}=\frac{dpdv}{d\tau}.$$

But, as before stated, the idea of work is more complex than that of pressure, since work is compound, being composed of two elements, pressure and space. We have, therefore preferred the form

$$\frac{dp}{d\tau}dv$$

and considering $\frac{dp}{d\tau}$ as the rate, v being considered as constant at first, then τ constant when v varies. It may be asked, "how can $\frac{dp}{d\tau}$ have a finite value when τ is considered constant?" It is only necessary to observe that $\frac{dp}{d\tau}$ is first found on the supposition that p varies with τ, and *afterwards* any value of τ may be assumed and fixed; or $\frac{dp}{d\tau}$ is the rate at which p was varying when τ was fixed.

Fig. 17 shows that for a given temperature the pressure is less for an imperfect gas than it would be if the same gas were perfect. In that figure $\frac{dp}{d\tau}$ may be considered as the tangent of the angle which a tangent line to the curve of pressures and temperatures makes with the axis of temperatures at the point whose abscissa is τ; and this trigonometrical tangent multiplied by τ gives an ordinate aq which being multiplied by dv gives an element of the work done, both external and internal. In this illustration a tangent to the curve Aca makes a greater angle with $o\tau$ than does oR, and the locus of q will be above OR.

We have

$$cq=aq-ac=p'-p=\tau\frac{dp}{d\tau}-p,$$

and the internal work for an infinitesimal enlargement of the volume, dv, will be

$$ds=\left(\tau\frac{dp}{d\tau}-p\right)dv,$$

$$\therefore\ s=\int\left(\tau\frac{dp}{d\tau}-p\right)dv,$$

which is equation (1A) of article 247, page 313 of the text. This is a partial differential equation in which we have thus far considered τ as constant, but making both τ and v independent variables, we have from the theory of differential equations the two partial differential equations

$$\frac{ds}{dv}=\tau\frac{dp}{d\tau}-p, \qquad (p)$$

$$\frac{ds}{d\tau}d\tau=\int\left\{\tau\frac{d^2p}{d\,\tau}+d\tau\frac{dp}{d\tau}-dp\right\}dv\frac{d\tau}{d\tau}$$

$$=\int\tau\frac{d^2p}{d\tau^2}dv\,.\,d\tau. \qquad (q)$$

Returning to our fundamental expression

$$\tau\frac{dp}{d\tau}dv,$$

it is stated on page 308 of our text that it may be negative, in which case Da, Fig. 17, will not be continuously convex in one direction, but may change its concavity as in Fig. 18, and we may have in the vicinity of such a point the values

$$-dp,\quad dp=o,\quad +dp,$$

and hence—since τ is never negative

$$\tau\frac{dp}{d\tau}=-,\ \tau\frac{dp}{d\tau}=o,\ \tau\frac{dp}{d\tau}=+$$

Thus, in the case of water from 32° to about 39° the internal pressure decreases, giving out, instead of absorbing heat. If through o a line be drawn parallel to the tangent at c, and ca be prolonged to meet it at q, we have

$$\tau\frac{dp}{d\tau}=-aq$$

and the internal work will in

$$(-aq-ac)dv=-cq.dv,$$

which, being negative, transforms it into external work.

If the substance be not homogeneous nor uniformly hot we have

$$W=\tau'\int\frac{dp'}{d\tau'}dv+\tau''\int\frac{dp''}{d\tau''}dv+$$

$$\&c=\Sigma\tau\int\frac{dp}{d\tau}dv,$$

in which each term is to be applied to so much of the substance as may be considered homogeneous and uniformly hot.

ENGINEERING NOTES.

The Great Alpine Tunnels and Subterranean Temperatures. — Among the many difficulties encountered in the execution of the works connected with the St. Gothard Tunnel, one of the greatest was the prevalent high temperature in the central section, 5 kilometers in length. The maximum temperature observed in carrying out the Mont Cenis Tunnel was 29.5° Centigrade (85° Fahrenheit), while a mean temperature of 29° (84.2° Fahrenheit) was confined to a section of 500 meters in the middle of the tunnel. During the execution of the St. Gothard Tunnel, at a distance of $4\frac{1}{2}$ kilometers from the southern end, and at $5\frac{1}{2}$ kilometers from the northern extremity, this temperature had been already attained, and at the time when through communication was established (February 29, 1880), the mean heat, extending over a section of the works, 5 kilometers in length, had risen to 31° (87.8° Fahrenheit), and on several occasions attained the maximum temperature of 35°. The air, which was considerably rarefied and much laden with moisture, proved very injurious to health—as many as 60 per cent. of the staff being on the sick list—while the horses died at the rate of 10 per month at each end, from a species of lung disease. As a necessary consequence the wages had to be raised 25 per cent., the working hours were reduced from seven to five per diem, and the costs were enormously increased. The limit of temperature at which underground work is still possible could not with certainty be ascertained. According to Du Bois-Reymond it may be assumed that at 50° (122° Fahrenheit), in air saturated with moisture, prolonged existence becomes impossible, though it appears very probable that even at 40° (104° Fahrenheit) this may be the case. The opinion of Dr. Giaconne that in the above works the limits of human endurance had been reached was shared by the staff.

The common law of increase of temperature in proportion to depth does not apply in tunnel construction; Dr. Stapff has, from observations on the St. Gothard Tunnel, propounded the theory that the increase of temperature above the mean temperature at the earth's surface, is represented by the formula $t=0.02068\,h$, or $t=0.02159\,n$, where h is the perpendicular height of the superincumbent mountain, or n is the distance inwards of a given point, on the plane passing through the longitudinal section. Stockalper has, in a different way, calculated the temperatures likely to be encountered in carrying out the Simplon and Mont Blanc tunnels as follows, reckoning from the northern end:

SIMPLON.

(About 22 kilometers in length.)

	Meters.	Probable temperature. (Centigrade).
4.0 kilometers in and a height of	1,400	30°
6.5 " " "	1,000	33°
9.0 " " "	2,050	36°
14.7 " " "	680	31°
17.0 " " "	1,734	31°
18.0 " " "	1,100	25°

MONT BLANC.

(18.5 kilometers in length from Taconnaz to Prés, St. Didier.)

	Meters.	Probable temperature. °
4.0 kilometers in and a height of	1,550	33
5.0 " " "	2,800	50
6.0 " " "	3,000	53.5
8.0 " " "	2,600	46
10.5 " " "	1,450	31
13.0 " " "	200	15

From these calculations he is persuaded that the execution of these tunnels will be impracticable on the systems hitherto adopted, and that it will be necessary to take very special precautions to guard against these excessive temperatures. Among other plans to be employed he mentions a bratticing to convey in air along the floor of the tunnel, use of compressed air for boring, introduction of ice into the workings, as also of streams of cold water; employment of quick lime to absorb the moisture, &c.; and he concludes that though it may be possible under certain conditions to execute the projected tunnel through the Simplon, the possibility of carrying out the proposed Mont Blanc Tunnel, under any circumstances, is open to the gravest doubt.—*Abstracts of Institution of Civil Engineers.*

Mekarski's Compressed-Air Engines on the Nantes Tramways—By Edmond Booa.—Mekarski's system of employing compressed air, heated by an admixture of steam, for the propulsion of tramcars has been in operation at Nantes for some years. The air compressors and saturating heaters are of the kind usually employed by the patentees. A comparison of the compressed air supplied to the car engines with the capacity of the compressing cylinders shows the efficiency of the air compressors to be 76 per cent. One kilogram (2.2048 lbs.) of air compressed to 30 kilograms (426 lbs. per square inch) supplies energy equivalent to 125,000 kilograms, or 90,-375 foot-pounds, and 100 kilograms are sufficient to propel a car of 8 tons weight for a distance of 12 to 14 kilometers (7.45 to 8.69 miles). The packing of the pistons of the second compressors proved troublesome, hard rubber rings and lignum vitæ did not stand, but satisfactory results have been obtained with manganese bronze. The tramcars at Nantes contain seats for 19 persons, a platform holding 15 or 16 at one end, and the heater and driver's cab at the other. The total length is 23 feet 3 inches, of which the heater and driver's platform absorb one-seventh; the width is 7 feet $2\frac{7}{8}$ inches. The total weight is 6 tons empty, and 8 tons filled, while the weight utilized for adhesion is $4\frac{1}{2}$ tons. The air is contained in ten cylindrical reservoirs placed underneath the platform, connected by pipes in two sets to form a working and a reserve battery, The contents of the former are 70 cubic feet, of the latter 28 cubic feet, holding together 220 lbs. of air at 426 lbs. pressure. The engines are attached to the outsides of the underframes, and enclosed in sheet iron covers. Their diameter is $5\frac{1}{4}$ inches, and the stroke $10\frac{1}{4}$ inches, and the cut-off takes place at one-third of the stroke. The driving-wheels are 27⅝ inches diameter. The cars are fitted with a Stilmant brake, worked by compressed air. The heater is placed vertically on the platform, and has a capacity of 27.7 gallons, the water being heated to 150° Centigrade by means of an injection of steam previous to starting. By connecting the car reservoirs with the stationary accumulators a pressure of 20 to 25 kilograms is obtained in the former, which are then connected directly to the compressing pumps, and the pressure brought to 30 kilograms, an automatic regulator turning the air again into the fixed accumulators when this limit has been reached. According to the state of the weather and the ability of the driver, the consumption of air varies, good drivers using at Nantes about 23 lbs. per mile, while inefficient men use up to 28.40 lbs. In 1883 the average consumption was 25.9 lbs., and during the first half of 1884, 24.6 lbs. The mean results obtained during the three years, 1881 to 1883, are given in the Table below:

	1881.	1882.	1883.
Car journeys.........	5,582	5,338	5,543
Kilometers run.......	701,934	384,324	397,066
Cost per kilometer:	F. C.	F. C.	F. C.
Drivers' wages.......	0.060	0.062	0.061
Staff at stations......	0.067	0.065	0.056
Fuel.................	0.117	0.117	0.101
Water................	0.019	0.020	0.020
Lubrication of rolling plant..............	0.010	0.011	0.013
Lubrication of fixed plant..............	0.007	0.007	0.006
Maintenance of rolling plant..............	0.064	0.092	0.093
Maintenance of fixed plant..............	0.020	0.028	0.024
Sundries.............	0.008	0.006	0.004
Total............	0.372	0.408	0.378

or 5.67, 6.25, and 5.76 pence per mile, respectively.

During the first half year of 1884 the cost of fuel decreased to 7.9 cents, and the total cost to 34.3 cents per kilometer, or to 5.22 pence per mile. The cost of horse traction of the three omnibus companies at Paris during the same three years was 0.612, 0516, and 0.513 cents per kilometer, or 9.39, 7.91, and 8.32 pence per tramcar-mile, This, however, includes a charge for renewal of horses, while it is not evident from the Table whether the maintenance of plant comprises a depreciation to provide for its eventual renewal, though the variations in the amount seems to indicate that depreciation or interest have not been taken into account in the calculation of the cost of traction.—*Abstracts of the Institution of Civil Engineers.*

IRON AND STEEL NOTES.

British exports of iron and steel to all countries in March aggregated 255,210 gross tons, as compared with 260,427 tons in March, 1885. A more favorable showing is made when the figures are compared with the previous months of this year, the exports in January having been 217,988 tons, and in February 225,475 tons. The exports of British iron and steel to the United States in March reached 57,684 gross tons, against 48,009 tons in February, and 48,496 tons in January, In the first quarter of this year 154,189 tons have been shipped to this country, as compared with 85,214 tons in the corresponding period of 1885. The increase is principally in pig iron, old iron, tinplates, and steel billets, slabs, etc.

On the 14th of April an Eastern syndicate, Messrs. Matthew and John Graff, of Pittsburgh, purchased the Fort Pitt Iron and Steel Works, at Pittsburgh, for the purpose of engaging in the manufacture of steel by the direct graphite process invented by Dr. C. J. Eames. By this process iron ore is broken into small pieces and mixed with 20 per cent. of Rhode Island graphite, a substance which heretofore has had no commercial value. The mixture is then placed in an ordinary heating furnace and reduced to a spongy mass at a low temperature, and it is claimed that the phosphorus and other impurities flow off with the slag. The experiments made the past winter have shown that it is only necessary for the sponge to be placed in pots and heated for a few hours, when it is ready for use. In all about ten hours are required to make good steel. The saving is so great that the new company is certain that the future is secure. Some improvements are to be made in the works, but it is expected that they will be ready for operation in the fall.—*The Bulletin.*

The Physical Constitution of Cast Steel.—Some interesting experiments with regard to the cellular structure of cast steel have been carried out at the Creusot works by M. Osmond and M. Werth. The experimenters found that, if the thinnest conceivable sheets of the metal are placed on glass and covered with nitric acid, the iron will be dissolved, while the skeleton remaining, revealing the distribution of the carbon in the steel, will, on examination by the microscope, furnish undoubted evidence that such distribution is by no means uniform, and that the cast steel consists of minute granulations in soft iron, separated, for the most part, by partitions made up of a different substance, a carburet of iron. In other words, cast steel is cellular in structure, the iron constituting the kernel, and the carburet of iron the shell. The elementary or simple cells thus constituted come together in composite cells or separate agglomerations in the thin sheets, which are thus rendered transparent by empty lines. These latter represent closed polygons of relatively large dimensions in the cast steel, but the polygons become smaller and broken up inproportionate to the more perfect manipulation of the metal.—*Iron.*

RAILWAY NOTES.

Lighting Railway Trains by Electricity—By Gustave Richard.—The object of this paper is to enumerate and describe the several ways in which it has been proposed to regulate and direct the movement of a dynamo when set in motion by power transmitted from the axles of railway-carriage wheels, so that this movement shall not be affected by the speed of the train or by the direction in which it is running. In the opinion of the author, the easiest way to drive a dynamo, independently of the movement of the train, would no doubt be to work it by means of a special and separate steam engine placed on the locomotive itself, and he thinks it probable that such will be the plan ultimately adopted for lighting complete trains; but amongst the systems hitherto tried he declares his preference for those which consist in placing accumulators in the guard's van, in addition to the dynamo deriving its power from the rotation of the wheels of the van in which it is used.

When it is not proposed to use either commutators or special regulators of the current, the first condition which requires to be met is the securing a constantly uniform rotation of the dynamo, whether the train be running forward or backward. Rogers (John Banting, 1881) proposed to effect this by means of belts giving motion to the dynamo in such a manner as to allow of their regulating the speed of, and, when necessary, reversing the action of the dynamo. The speed he would regulate by passing a belt over two cones, one of them inverted and standing on its apex; so that by raising or lowering it the belt is tightened or loosened on the cones. Above one of these cones, and revolving on the same axis, is a pulley-block, from which the driving-belt passes to the dynamo, and when the motion of the carriage wheels is reversed, a ratchet shifts the position of the pulley, and gives a reversed action to the driving-belt.

Mr. Tommasi, in 1882, proposed a variety of expedients for simply interrupting the revolutions of the dynamo as soon as the motion of the train was reversed. One of these consisted in attaching to the axle of the carriage a small wheel working by friction against a second, over which the driving-belt passed, and arranged so that on the carriage ceasing to advance, or on its motion being reversed, the friction between the two wheels would cease, and the dynamo stop working. By a second plan the same effect was to be produced by the automatic action of a hammer and catch. Mr. Eli Starr, of Philadelphia (1882), proposed to place one wheel on the axle of the carriage, another above it on the axis of the dynamo, and a third between the two which, when pressed against them by the admission of some of the compressed air used with a continuous brake, would cause both to revolve, but would again separate from the other wheels whenever the brake of the train came into use.

Messrs. W. H. Preece and J. James (1882) would give motion to a generating dynamo by means of compressed air continuously provided to a chamber by means of air pumps worked by eccentrics connected with the carriage axles; but the author objects that the clouds of dust raised upon the railway would choke the action of the pumps, and render such an arrangement impracticable.

He is of opinion that all the above described plans are more or less imperfect, and that the requisite regulation of the current could be better effected electrically by using the accumulators for the purpose or by shifting the electrical contacts, than by any mechanical contrivances. Several such arrangements have been proposed by Messrs. Stern and Billingsby, and by Mr. Tommasi and others.

One ingenious plan devised by Messrs. Stern and Billingsby consists in making the dynamo, on its rotation being reversed, cause the positive and negative poles of the circuit to change places; another consists in charging alternately two separate series of accumulators, and at regular intervals using, first the one and then the other for lighting the lamps. Mr. Tommasi obtains a similar result by interposing a resistance varying with the speed at which the dynamo is running, and thus furnishing a substantially constant current to the lamps, whilst the excess only of the current passes into the auxiliary accumulators; and Mr. Calo interposes in the circuit by which the lamps are supplied, a series of accumulators which are acted upon in more or less number according as the speed of the dynamo increases or diminishes. Mr. Tommasi has also more recently advocated the use of a small auxiliary dynamo, which when not required for keeping up the supply of a continuous and sufficient current to the lamps, should be used for maintaining a full charge in the accumulators It is, however, pointed out by the author that if the action of these dynamos were independent of the movement of the train, there would be no further need for any of these rather complicated arrangements, and that even the accumulators might in that case be dispensed with.—*Abstracts of Institution of Civil Engineers.*

RAIL-TESTING IN RUSSIA—By N BELELUBSKY.—Since 1878 the Russian Ministry of Ways and Communications has enforced the following conditions for the testing of iron and steel rails.

The whole supply of rails is first to be inspected and their dimensions checked. After the removal of defective rails the rest are to be piled in stacks of 1,000 rails each. From each of these stacks the Government inspector is to choose three rails, from each of which three test pieces six feet in length are to be carefully cut.

Of the three test pieces one is to be subjected to a pressure test and the other two to a striking test. If the testing takes place at a higher temperature than from 0° to 10° Fahrenheit, two at least of the pieces must undergo the striking test reduced to that temperature. The cooling is done by surrounding the rail in a wooden box, 9 feet 4 inches by 3 feet by 2 feet, with a mixture of ice and salt. The temperature of the rail is measured by a thermometer, placed in a hole bored in the end of the rail and filled with mercury.

1, *Test for Bending under Load.*—The piece to be tested is laid on supports 3 feet 6 inches apart, and subjected for five minutes to the application in the middle of the load A (see Table) when the deflection must be not less than 0.12 inch (3 millimeters) on removal of the load, but the permanent set not more than 0.08 inch (2 millimeters). The weight is to be applied twice, and after the second applicatiou the permanent set must not exceed 0.08 inch.

2. *Bending Test with Increased Load.*—Pieces which have stood the first test are to be subjected to the load B (see Table), which they must support for five minutes without breaking.

3. *Test by Falling Weight.*—The remaining two pieces of the same rails are to be placed on the supports, and after two strokes from a weight of 923.7 lbs. falling from a height H (see Table), must not show any external signs of fracture.

4. *Test of the Goodness of the Material.*—All pieces which have stood the above tests are put under the same hammer, falling from H+1, H+2, &c., feet until they break.

Note.—The testing apparatus is made to a normal pattern, and the site for its erection is chosen by the inspector. The metal base must weigh not less than 19.7 tons, and the bottom of the stone foundations must be not less than 4 feet 6 inches below the surface of the ground.

The following Table gives the values of A, B and H, referred to above, for various weights of normal steel and iron rails:

	Weight per yard.	Load A.	Load B.	Height H.
	Lbs.	Tons	Tons.	Feet.
Steel	46.4	9.00	13.92	4.75
	50.4	11.06	16.38	5.65
	54.4	13.10	19.66	6.50
	58.5	15.15	22.52	7.50
	64.5	17.20	25.39	8.50
Wrought iron	54.4	9.00	11.47	4.00
	54.4	11.06	13.51	4.55
	64.5	13.10	16.38	5.25
	70.6	15.15	20.07	6.00

If more than a third of the pieces do not stand the tests all the thousand rails from which they have been taken are rejected, but if a third, or less than a third fail, it is permitted to re-divide the stack of one thousand into lots of two hundred to three hundred, and make the acceptance of these depend upon the tests of at least two rails from each stack.

The putting aside of large quantities of steel rails from year to year, in consequence of breakage or wearing out, suggested to the Imperial Russian Technical Society in St. Petersburg to contribute, by examination of the removed rails, to the discovery of the causes which influence the life of rails; and especially with a view to finding whether the present testing regulations require alteration, and whether harder or softer material is to be preferred for rails. To forward these investigations nearly all the Russian railways sent to the Technical Society a large number of samples of rails and tires, with statistical notes referring to each.

Although these investigations were commenced by the Technical Society as a private undertaking (with, however, the support of the railway management), the work received official recognition in 1884 from the Ministry of Ways and Communications, and the convention of representatives of steel-works and of railway managers called together by this Ministry decided to defer until the conclusion of the first series of investigations the answering of the question whether the regulations for testing and accepting rails which have been in force for the last seven years required to be altered or not? This first series consists in the examination of worn rails and tires. The results will be put together in the graphic form. A further series of investigations is planned, in which steel rails of different degrees of hardness, furnished by Russian steel works, will be laid in and periodically inspected by the commission.

The following are the alterations in the regulations for the acceptance of rails suggested by the Management of the State Railways in conjunction with the Commission of the Imperial Technical Society.

1. In the bending test with load A the maximum permanent set shall be 0.04 inch (1 millimeter), instead of 0.08 inch (2 millimeters), and no demand need be made as to elasticity.

2. The test for beuding with increased load B may be omitted.

3. If the temperature of the air is below 9.5° Fahrenheit, no artificial cooling need be applied.

The following is the programme of the investigation now going on:

A. Data to be collected by the railway management: (*a.*) Type of rail, name of works, mark and year, original weight per running foot. (*b.*) Load ou the axles of engines running upon the line. Gross tonnage passing over the rails. (*c*) Weight of rail when taken up. Cause of failure: broken (time, place, on or between the cross-sleepers); not broken but worn out. (*d.*) Position of the rail in the line: in straight or on curve (radius, inner or outer line), level or on gradient, quality of ground and ballast. (*e.*) Life of rail.

B. Ministerial tests: Striking and bending, carried out by the Commission at the Putiloff works (St. Petersburg). (*a.*) Bending test: loading in press; deflection, permanent and temporary. (*b.*) Striking test: temperatnre of the tested rail; height of fall of the monkey ($1\frac{1}{2}$ ton in weight). Deflection at first and second blow.

C. Tearing test, carried out in the mechanical laboratory of the Road-Construction Engineers Institution. (*a.*) Tensile strength (R), relative extension (i), contraction (c) at fracture. Product Ri and sum $R+c$.

D. Torsion test, carried out at same place as C. Limit of elasticity, shearing strength, work at limit of elasticity and at fracture.

E. Quantitative analysis, carried out in the chemical laboratory of the Finance Minister. Percentage of carbon, manganese, silicon, phosphorus, sulphur.—*Abstracts of Institution of Civil Engineers*,

RAILWAYS OF EUROPE.—According to a statement in a recent *Revue Generale des Chemins de Fer*, the length of railways open for traffic in Europe, on December 31st, 1884, as compared with the mileage open at the same date in 1883, Germany heads the list with 36,737 kilos. of railway, as against 35,908 kilos. in December, 1883; increase during the year, 829 kilos., or 2.31 per cent. Next follows France with 31,216 kilos., against 29,714 kilos.; increase, 1,502 kilos., or 5.05 per cent. Great Britain and Ireland, 30,514 kilos., against 30,179 kilos.; increase 1.11 per cent. Russia and Finland, 25,391 kilos., against 24,888 kilos.; increase 503 kilos, or 2.02 per cent. Austria, 22,016 kilos., against 20,857 kilos.; increase 1,249 kilos., or 5.99 per cent. Italy, 9,925 kilos., against 9,445 kilos.; increase 470 kilos., or 4.97 per cent. Spain, 8,663 kilos., against 8,251 kilos.; increase 412 kilos., or 4.99 per cent. Sweden and Norway, 8,162 kilos., against 7,960 kilos.; increase 202 kilos., or 2.54 per cent. Belgium, 4.319 kilos., against 4,273 kilos.; increase 46 kilos., or 1.08 per cent. Switzerland, 2,761 kilos., against 2,750 kilos.; increase 11 kilos., or 0.40 per cent. Holland and Luxemburg, 2,654 kilos., against 2,521 kilos.; increase 133 kilos., or 5.28 per cent. Denmark, 1,944 kilos., against 1,813 kilos; increase 131 kilos., or 7.23 per cent. Roumania, 1,602 kilos., against 1,520 kilos.; increase 82 kilos., or 5.39 per cent. Portugal, 1,527 kilos., against 1,494 kilos.; increase 33 kilos., or 221 per cent. Turkey, Bulgaria and Roumelia do not show an increase in the mileage of their railways during 1884, which had a length of 1,394 kilos. in December, 1883; nor do the railways of Servia, with 244 kilos. Greece, on the contrary, increased her railways from 22 kilos. in 1883, to 175 kilos. in 1884. The total length of European railways on December 31st, 1884, was 189,334 kilos., compared with 182,999 kilos. on December 31st, 1883. The aggregate increase was 6,335 kilos., or 3.46 per cent.

ORDNANCE AND NAVAL.

BURMESE ARMS.—Long matchlocks, with very small stocks, are the only Burmese firearms, besides the short, broad cannon used in salutes. The former carry a long distance, and are not fired from the shoulder, but from the side of the head, nearly on a level with the ear. Attached to the small square embroidered bag that every Shan carries over his shoulder, is a small powder-flask of the shape of a miniature horn, flattened and distended at the point, which is open, but has a flat piece of horn which fits into it, and is prolonged backwards across the curve of the flask, to the base of which it is firmly fastened. Downward pressure on the free portion over the curve raises the lid-like anterior extremity of this primitive spring, and allows the powder to run out in driblets. More capacious powder-flasks are made of the horns of cattle, but they are only used on a long expedition. They are suspend from a broad red belt, ornamented with lines and rosettes of cowries, and with tufts of red hair round the margins. The horn of the serrow, artificially sharpened at the point, is usually found attached to the shoulder-bag, and is used as a borer, while its base may be bound with brass, and closed with a lid as a lime or opium box.

A description of the costume of the Shans generally, would be very incomplete were the dáh unnoticed. This has a blade 2½ feet to 3 feet long, gradually expanding from the hilt towards the almost square point, which is about 2½ inches broad. The handle is of wood, bound with cord, and ornamented with silver foil, with a tuft of red goat's hair stuck in the hilt. The wooden scabbard covers only one side of the blade, and a hoop of rattan, bound with red cloth, is attached to its upper third, and worn over the right shoulder.

The Kakhyens have a very ingenious way of striking fire by the sudden and forcible descent of a piston in a closed cylinder. There is a small cup-shaped cavity at the end of the piston-rod into which tinder is inserted. The piston is then introduced into the cylinder, which it tightly fits, and by a blow is made to descend with great rapidity and force, and is as rapidly withdrawn, when the little pellet of tinder is found to have become ignited: a beautiful but simple experiment, illustrating the evolution of a very large amount of heat by the sudden compression of the air in the piston. These instruments are not more than four inches long, and are in general use.

THE STRENGTH OF RIFLED GUNS.—The author deals with the French artillery and its steel guns of the period 1861 to 1870. Guns of above five inches bore only are referred to, as that at this time there was no question of the strength of guns of smaller calibre. After describing the trials of guns of various modes of construction, the author shows that up to 1870, the manufacturers could not deliver steel-blocks from which a safe gun could be constructed.

The second section embraces the period 1872 to 1875, and describes the trial of two guns of 9.44 inches bore, the results of which showed that though great improvements had been made in the manufacture of steel since 1868, still in 1872–3, it was not sufficiently advanced to insure good tubes of all calibres, or jackets for guns of 9.4 inches bore suitable for service, and in fact that the strength of steel guns of that date was not superior to the cast-iron guns of 1870 then in service.

Section iii. treats of the period 1875–81. Refers to the offer of the Creuzot firm to make a steel gun of 100 tons weight, to be placed in the Paris Exhibition of 1878, and purchased by the French Government at 2s. 8½d. per lb., and after trial, an order for ten more to be given at 1s. 11d. per lb. General Frébault's protest against the proposal is quoted at length, with his offer to construct a gun of equal strength, of cast-iron tubed and hooped, at a cost of 5.45d. per lb. Though the Creuzot offer was not accepted, it was decided from that date —1875—to make all the large guns of the fleet of steel.

The trials and mode of construction of various guns of from 10.6 inches to 16.5 inches bore are described. The latter was only delivered in 1882, as the Compagnie Forges de St. Chamond were obliged to erect an 80-ton steam-hammer to enable them to make the gun. The author considers that up to the time of the erection of this hammer, and the trial of the 16.5 inch gun, the introduction of steel had increased the cost of guns threefold, without any increase in ballistic effects. The armament of the fleet was retarded several years, and to avoid risks, unusual precautions, which were superfluous for iron guns, had to be taken.

Section iv. gives the period 1881–5 with few details, but notes the improvements in quality and regularity of the steel supplied by French firms, draws comparisons between the comparatively small bores of 1881, and the larger bores of 1875–9, also the lengths of the guns; concluding with the statement that as regards steel guns the French artillery is in a state of advancement and certainty whilst foreign countries are in an experimental stage.

Passing on to foreign countries and giving a *resume* of the histories of the Whitworth and Krupp systems (the former only to 1876), he divides the latter into five periods—1851–68, 1869–72, 1872–77, 1879–82, 1882–85. The principal trials and manufactures of these periods are noted, the information being drawn from numerous sources, principally the Prussian Government trials. The introduction of the brown cocoa powders is here noticed, and the consequent reduction in pressure as compared with the old iron guns.

Referring to foreign nations, nearly all of which, whilst recognizing and using steel, have no definite models for their artillery. England is stated to be in a transition state, reference is made to the report of the 1883-4 United States Committee on the Elswick works, and the bulk of this section is taken up with extracts from and remarks on Colonel Maitland's paper read read at the United Service Institution on the 20th of June, 1884. Italy is next taken, and the large guns made by Armstrong are described and criticised.

Russia, at the time of writing, was only in an experimental stage, also the United States.

The Gonzalez Hontoria guns of the Spanish navy are described and illustrated.

The period of guns made with coils of wrought iron is reviewed, and the bursting of the 38-ton Woolwich, 100-ton Armstrong, and 6-inch "Active" guns are discussed.

In the last chapter, guns on various systems are noticed, including bronze, wrought iron, Longridge, Hope and Ordoner guns. These are noted, not because of results of extended trials, "but because they indicate new lines of experiments, abandoned ideas, or more or less beaten tracks which lead to no issue, and should be avoided." In conclusion, the author enforces the opinion that in artillery matters, the best text-books are of no value; but that practical and continued trials are the only lines on which it is safe to rely.—*Abstracts of Institution of Civil Engineers.*

BOOK NOTICES.

Publications Received.

Report of the Commissioner of Navigation for 1885. Washington: Government Printing Office.

Manufacture, Consumption and Production of Iron, Steel, and Coal in the Dominion of Canada. By James Herbert Bartlett. Montreal: Dawson Brothers.

Annual Report of the State Geologist of New York, for the year 1885. Trenton: John S. Murphy.

Sanitary Engineering. By William Cain, C.E., Raleigh, N. C.: P. M. Hale.

The Manufacture, Consumption and Production of Iron, Steel and Coal in the Dominion of Canada. By James Herbert Bartlett. Montreal: Dawson Brothers.

This work is mainly statistical, but as it records the history of the beginnings of some important industries it will be found interesting.

The history of the first iron works in Canada, the St. Maurice Forges, is first concisely sketched, and is followed by brief accounts of other works in the Province of Quebec.

Early enterprises in Ontario form the subject of Chapter III.

Chapter IV. deals with smelting in New Brunswick, and Chapter V. with the manufacture of iron in Nova Scotia.

A general account of the iron trade in other countries is given as a concluding chapter, and is added to enforce the idea that the further development of these industries is of the greatest importance to the Dominion.

The Theory of Equations. By William Snow Burnside, M.A., and Arthur William Panton, M.A. Second edition. London: Longmans, Green & Co.

The earlier edition of this work is familiar to most advanced students of pure mathematics. The present edition differs chiefly in the expansion of certain chapters, which, bearing the same titles as before, are considerably enlarged. Chapter XI., Determinants; and Chapter XVI. on Transformations, exhibit the most marked changes.

The entire list of chapter headings is: General Properties of Polynomials, General Properties of Equations, Relations between the Roots and Coefficients of Equations, Transformation of Equations, Solution of Reciprocal and Binomial Equations, Algebraic Solution of the Cubic and Biquadratic, Properties of the Derived Functions, Limits of the Roots of Equations, Separation of the Roots of Equations, Determinants, Symmetric Functions of the Roots, Elimination, Covariants and Invariants, Covariants and Invariants of the Quadratic, Cubic and Quartic Transformations, The Complex Variable.

Electro-Deposition. A Practical Treatise on the electrolysis of Gold, Silver, Copper, Nickel, and other Metals and Alloys. With Several Chapters on Electro-metallurgy. By Alexander Watt. London: Crosby Lockwood & Co. 1886.

This closely printed manual of 500 pages, with numerons illustrations, gives detailed information on the subjects treated of. The author is evidently an expert in a majority of the processes, and, when not so, gives descriptions, generally verbatim, from original authorities. The work contains accounts of the most recent processes, and, especially in the chapters on metallurgy, will be found both interesting and instructive. Smelting and refining by electricity is in the case of many metals—gold, silver, copper, lead, zinc—superseding the older and rougher methods. The gain in economy from cheapness of plant, chemical purity of product, profitable disposal of by-products, as well as safety and improved hygienic surroundings of the operators, recommend them highly; besides this, to them we owe our present supplies of the new alloys of alluminium and silicon bronzes. The chemistry of the different processes is satisfactorily explained. There is also given a brief account of the modes of developing the current, beginning with the original contrivances of Volta, the several chemical batteries, the magneto-electric machine, the dynamo, and, finally, thermo-electric piles. The descriptions of these machines may probably be found satisfactory to amateurs and workmen. Scientific men will observe many defects, and we think much of this matter might with propriety have been omitted. In thermo-electricity we think the author does good service in emphasising the immense possibilities lying hid therein. In no work have we seen this field of practical science so truly estimated, as undoubtedly the most theoretically perfect mode of collecting for mechanical uses the very elusive molecular forces of heat. The book also gives a brief account of the history of the art, and in interesting quotations from contemporaneous journals affords a glimpse of the excitement aroused by the announcement of the discovery of the successive processes which have now become so familiar and commonplace—such excitement as the older of the present generation may remember some years later caused by the discoveries of Talbot and Niepce in photography, or more recently those of Edison, Varley and Bell in the phonograph and telephone.—*Iron.*

This book opens with three historical chapters, giving an account of the rise and progress of Voltaic electricity—without mention of the anticipation of Galvani's initial experiment by the illustrious Dutch naturalist, Swammerdam—of electro-magnetism, magno-electricity, dynamo-electricity, and thermo-electricity, which latter Mr. Watt believes has before it a great future, the thermo-pile being the only example of the direct conversion of heat into electric energy, and as far as is known this is generated without any other waste beyond that of the fuel consumed in generating the heat necessary.

The fourth chapter gives from original sources, the history of electro-deposition. Our readers will doubtless be surprised to learn that the earliest successful experiments were made by Sir H. Bessemer when a youth of eighteen, anticipating Jacobi by about seven years, and that Jordan was the first to publish a definite process.

In the fifth chapter we find a theory of electrolysis, whilst in the following section there is an examination of electrical theories in their relation to the deposition of metals. The processes for coppering, gilding, and silvering are next expounded with great minuteness.

The electro-deposition of nickel, tin, iron, zinc, and some of the metals less generally used is next considered, followed by instructions for the deposition of alloys, such as brass, bronze, and German silver.

We have then three chapters on electro-metallurgy, under which head rank processes for refining copper and lead; for the electrolytic refining of gold, silver, and copper ores, and for the electro-chlorination of gold ores.

In conclusion follow chapters on some mechanical operations subsidiary to electro-deposition, on the recovery of the precious metals from waste solutions, and on stripping metals from each other.

A separate chapter is devoted to the consideration of the chemical agents used in the electro-plastic art.

Under the heading "Useful Information" Mr. Watt gives hints on the management of batteries, their relative power, intensity, and constancy; tests for free cyanide, and remedies in case of poisoning. Such information is exceedingly valuable to all persons obliged to manipulate so formidable a poison as potassium-cyanide. Accidents from this substance are not unfrequent in electro-plating works. Indeed, the author confesses to having been three times placed in some danger by swallowing a solution of cyanide, or inhaling its fumes. He recommends that the coldest water procurable should be poured upon the head and allowed to run down the spine of the sufferer, whilst ammonia or bleaching lime is cautiously applied to the nostrils. He even recommends that this acid should never be used without a second person holding a phial of one of these agents near the nose of the operator. We should recommend as a more excellent way to hold the breath entirely whilst pouring out hydrocyanic acid from a bottle, or never to work with it except under a good draught-hood.

Mr. Watt's work will be very serviceable to technical students, to apprentices, workmen who are seeking to qualify themselves for more responsible positions, and, if we may venture to say so, to manufacturers who feel the necessity of discarding rule-of-thumb and combining in future practice with theory.—*Chemical News.*

MISCELLANEOUS.

An Asian California.—A letter from St. Petersburg in the *Journal des Debats* gives a description of the new California, as the new gold mines discovered in the valley of the Djolgute River are called. This valley is upon the Chinese bank of the Amoor, opposite the Russian Colony of Tgnachino, and as the soil is very marshy, and there are no roads, it is only accessible in winter. Gold was first discovered there in May, 1884, and it soon attracted a great many adventurers, the earliest comers being Russian deserters and escaped convicts from Siberia, and by the month of January in last year there was a colony of 9,000 Russians, the total having been very much increased since, while there are also about 6,000 Chinese and 150 adventurers of different nationalities, the last-named of whom have joined the Russians, the organization of the colony being altogether Russian. The gold-finders are divided into 722 artels (small groups) of workmen, all of whom are absolutely equal. These artels elect twelve elders (starchina), who do not work themselves, but superintend the diggings, and receive a salary of 200 roubles a month. They are selected from among the dealers in gold and tavern keepers, and form a sort of district police corps. They do not meet with any interference from the Chinese authorities in this remote valley, the laws of which are very simple but severe, the penalty of death being inflicted for cheating at play, for adulterating the gold dust, or for theft; while flogging is inflicted for drunkenness during the hours of labor or for bringing females into the colony. Since the foundation of the colony there have been only three murders and two inflictions of the death penalty, a Russian having been hung for adulterating the gold dust, and a Jew flogged to death for having spread false news as to the approach of a body of Russian troops, hoping thereby to send down the price of gold, owing to the panic. There are twenty-seven taverns in the colony, and, owing to the competition, the prices are not high, except for spirits. The gold-fields, which are 25 miles in length by 3 miles broad, are said to be very rich, and 7 lbs. of gold are obtained from 32 cwt. of gravel, even with the primitive mode of washing adopted there.

LIQUID FUEL FOR STEAMSHIPS.—The system of oil-burning apparatus recently described by us as having been fitted on board the Himalaya steamship has been applied to a vessel recently launched by Messrs. Wigham, Richardson & Co., of Newcastle-on-Tyne. The steamer, which is intended for the Black Sea trade, and to be permanently oil-burning, has her water-ballast tanks divided up, and made available for the storage of her fuel. She has also other storage tanks built into the ship on each side of the engine-room, all these being connected by pipes to the small feed-tanks situated above the boiler. A large supply pipe connected through valves to the storage tanks allows of the vessel being filled up with fuel in a very short space of time. The oil-burning apparatus has been fitted by the Tarbutt Liquid Fuel Company, of 75 Lombard Street, London, and is similar to that adopted on board the Himalaya, which recently made her successful trial trip from London to Granton and back on the new fuel. A trial of the apparatus has just been satisfactorily completed at Messrs. Wigham, Richardson & Co.'s works, which was attended by representatives from some of the leading ship-building and engineering works on the Tyne, who are evincing great interest in this most recent development of the liquid fuel question. A number of applications of this system are now being made to marine and stationary boilers, stills, and plate-heating furnaces.—*The London Times.*

METAL WORK OF THE BURMESE.—Both Burmans and Shans are expert blacksmiths. The latter forge all the *dahs* (native hatchets) used by themselves and their neighbors in the Hotha valley, and they annually resort to Bhamo, and the villages in the Kakhyen hills, for the purpose of manufacturing them. Their bellows are of the most primitive stamp, consisting of two segments of bamboo, about 4 inches in diameter and 5 feet long, set vertically, forming the cylinders, which are open above and closed below, except by two small bamboo tubes, which converge and meet at the fire. Each piston consists of a bunch of feathers, or other soft substance, which expands and fits tightly in the cylinder while it is being forcibly driven down, and collapses to let the air pass as it is being drawn up. A boy, perched on a high seat or stand, works the two pistons alternately, by the sticks serving as piston rods. Charcoal is used for fuel.

The casting of large and small articles in brass, bronze, and other alloys is much practiced, always adopting the method known as *à cire perdue.* First, a clay model is made, and coated with beeswax to the thickness of the intended cast, and again covered with an outer skin (2 inches thick) of clay, mixed with finely-chopped straw; this latter coat is provided with funnel-like holes, for pouring in the molten metal, at intervals of 4 inches, and with straw-holes for letting out imprisoned air. Holes are also provided at the bottom for the escape of the melted wax.

A NEW sweetening agent has been produced from coal-tar. It is known to chemists as "benzoyl sulphuric imide," but it is proposed to name it "saccharine." The discoverer is Dr. Fahlberg, a German chemist in America, and its preparation and properties were recently described by Mr. Ivan Levinstein at a meeting of the Manchester Section of the Society of Chemical industry. Saccharine presents the appearance of a white powder, and crystalizes from its aqueous solution in thick short prisms, which are with difficulty soluble in cold water, but more easily in warm. Alcohol, ether, glucose, glycerol, &c., are good solvents of saccharine. It melts at 200 deg. Cent., with partial decomposition; its taste in diluted solutions is intensely sweet, so much so that one part will give a very sweet taste to 10,000 parts of water. Saccharine forms salts, all of which possess a powerful saccharine taste; it is endowed with moderately strong antiseptic properties, and is not decomposed in the human system, but eliminated from the body without undergoing any change. It is about 230 times sweeter than the best cane or beetroot sugar. The use of saccharine will therefore be not merely as a probable substitute for sugar, but it may even be applied to medicinal purposes where sugar is not permissible. One part of saccharine added to 1,000 parts of glucose forms a mixture quite as sweet as ordinary cane sugar. The present price is 50s. per pound; but although very high, this is not prohibitory, as its sweetening power is so great; but it is very probable the cost of its manufacture will soon be very considerably reduced. The *Brewers' Guardian* says: "This new compound will be of great interest to brewers, for not only is it perfectly wholesome, but it possesses, in addition to its intensely sweet taste, decided antiseptic properties, and therefore may be usefully, safely, and advantageously added to beer."

Carbonic Acid in the Liquid and the Solid State.—The employment of liquefied carbonic acid gas for various manufacturing operations has resulted in the development of a new industry. For many years after Davy and Faraday had succeeded in effecting the liquifaction of this gas, and even after Natterer, of Vienna, had devised a special apparatus for the purpose, the process was regarded merely in the light of a lecture experiment, and was only usefully employed for the production of very low temperatures The author first turned his attention to the subject in connection with the plans for raising the armor-clad ship, the Grosser Kurfürst in 1878. His first practical experiment in this direction was carried out at Kiel in 1879, when, by means of about 40 kilograms of liquid carbonic acid enclosed in a receiver, to which was attached an empty balloon formed of sail-cloth coated with india-rubber, a block of stone weighing 316 centners (16 tons) was raised to the surface in eight minutes after the tap opening the communication from the receiver to the balloon was turned by a diver. The success of this experiment led to the proposal to found a company for the raising of sunken vessels on this system, but the scheme came to nothing, partly because of the difficulty at that time of producing the liquid in large quantities at a cheap rate.

Subsequently, Mr. F. A. Krupp, of Essen, used this fluid for the production of low temperatures for shrinking out the cores of cannons, and for the compression of molten metal in the molds. He obtained in this way a pressure of 75 atmospheres, and was able to produce much more solid and dense castings than before. In consequence of the steady improvement in the pumping apparatus employed at Essen for the compression of the gas, and the production of the liquid in large quantities, it became possible, owing to its cheapness, to make use of it for beer-raising and in the manufacture of artificial mineral waters.

In process of time the firm of Kunheim & Company, of Berlin, took the matter in hand and turned the scientific facts to industrial account. Their business was taken over by the Berlin Company for the Carbonic-Acid manufacture, which has been most successful, and now produces daily eighty cylinders, each containing 8 kilograms, or 640 kilograms (1,411 lbs.) of liquid carbonic acid, equal to 320,000 litres of gas.

This is employed for beer-raising in the same way as compressed air was formerly made use of. The cylinder of liquid is attached to a receiver, and on turning the tap connecting the two vessels the liquid rushes in, and expands in so doing into the gaseous form. In a few seconds this gas attains a pressure in the larger vessel of 1½ atmosphere, and the tap is then closed. The pipes conducting to the beer casks are subsequently opened, and the carbonic acid gas flows into the casks with a pressure sufficient for the drawing off of the beer. As only pure carbonic acid gas passes into the beer-casks all putrefactive processes are avoided, and the beer is drawn in a bright and sparkling condition. Eight kilograms of the compressed gas are sufficient for the delivery of 24 to 30 hectolitres of beer.

The pressure exerted by liquid carbonic acid varies in accordance with the temperature; thus:

			atmosphere.
at—79° Centigrade	the pressure	=	1.2
" —10° "	"	=	27.5
" + 5° "	"	=	40.5
" +20° "	"	=	58.8
" +30° "	"	=	73.0

All danger in the storage of the compressed gas is avoided by the testing of the cylinders (which are made of wrought iron) to 250 atmospheres before they are filled, and the receivers are furnished with a safety-valve, weighted to a little over 1½ atmosphere pressure, and these are all tested to 5 atmospheres. Although between six and seven thousand cylinders of the liquefied gas have been sent out, and have been used for the most part by unskilled persons, there have been no accidents of any kind The price of a cylinder of the liquid is 16 marks (16s).

By removing the pressure or allowing the liquefied gas to escape into a woolen bag an intense cold is produced, and a sufficient amount of heat is abstracted to cause a portion of the remaining liquid to freeze into crystals, resembling snow. These frozen needles can be brought, by means of slight pressure, into solid lumps resembling chalk, which are specifically heavier than water, and which by increased pressure can be obtained of a specific gravity of 1.5. By surrounding this solidified carbonic acid with a bad conductor it may be preserved for as much as fifteen hours, during which time it is, of course, being gradually dispersed in the gaseous form.—*Abstracts of Institution of Civil Engineers.*

At the Edinburgh (Scotland) International Exhibition, which is to be opened in May and continue till October, the manufacturers of Sheffield are to be worthily represented. An Exhibitors' Committee has been formed, and many of the most skilled artisans of the town have responded to the invitation to exhibit, with the result that in many departments there will be a capital show of Sheffield's high-class work. A good position—what the Committee consider the most prominent and best position in the artisan section of the Exhibition—has been secured for the Sheffield workmen. It is intended to have examples of old Sheffield work placed side by side with the specimens of skill made by modern artisans.—*The Engineer.*

VAN NOSTRAND'S

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TREATISE ON THE THEORY OF THE CONSTRUCTION OF HELICOIDAL OBLIQUE ARCHES.*

By JOHN L. CULLEY.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

III.

CHAPTER V.

METHOD OF WORKING THE VOUSSOIRS AND SKEW-BACK STONES.

47. It should be observed of the several faces of a voussoir that, while its soffit face and extradosal are warped curved surfaces, the bedding surfaces are radial warped surfaces. On this account and because they are generally considerably wider than the soffit faces, the bedding courses are the most presentable for the first surfaces to be worked.

48. The curve of the templets of the intradosal and extradosal coursing joints may be obtained exactly by the method described in Article 12. In practice, however, the elliptical curve, S″3.4.5R″ (Fig. 4.), will be sufficiently exact; for when the length of the voussoir is small in comparison with the length of the whole semi helix, the curve will vary but slightly from this elliptical curve. Very sharp oblique arches of small diameter have been successfully built, where this curve has been regarded as circular arcts, the method of determining such circular arcts is described further on, in Articles 52 and 53. The elliptical curve is nearer the true spiral curve, of course, than the circular arcs are. But neither of these two approximate curves should be employed unless it is found, after careful comparison, not to materially depart from the true curve.

49. Let A B C D E (Fig. 19) be the elevation, and E D the plan of a templet of a soffit coursing joint, so that the curve A B C between the center lines of the iron strap, 1 and 3, will be the exact length of a voussoir soffit coursing joint. We will suppose the rules shown in Fig. 7 are the proper ones for the joint A B C at points on it equidistant apart, and that the voussoir bed warps from A H towards C J, the point J being the point in the bed farthest from a plane passing through the point A C and H. Evidently the parallel rule should be applied at A and the twist rules at B and C, so that their sides will be normal to, and their upper edges shall coincide with the sight plane 4 5.

The iron straps 1, 2 and 3 are fastened to the templet A B C D E so that their center lines here shown will be normal to the curve A B C, but their sides are normal to the plane 4 5. Their tops, like their rules, coincide with this plane 4 5. Let each of the three rules above referred to, at their intradosal points A B and C, be extended over the templet A B C D E an arm that will exactly fit into its respective strap 1, 2 or 3 (Fig. 20). Thumb screws in the top of iron straps will prevent the templets moving when they are once adjusted to these straps. The cross section of the parallel and twist rules should be of the form shown at K L in order that its lower edge may occupy the least space.

50. Therefore, in working the coursing bed of a voussoir, apply the soffit joint templet (Fig. 19) to the surface of the stone from which the voussoir is to be cut. It should be applied to the stone far enough from the edge of the stone to allow for the working of the soffit surface of the voussoir in the stone afterwards. When the surface of the stone has been dressed off to receive the templet let the curve A B C be marked upon it. Cut a narrow channel across the stone at A H so that its bottom surface shall exactly receive the lower edge of the parallel rule when properly adjusted in its strap 1, Fig. 20, and the soffit joint templet coincides with its curve already marked on the dressed surface of the stone. Then cut a narrow channel across the stone at B I, so that its bottom surface will exactly receive the lower edge of its twist rule, when this and the parallel rule, properly adjusted to the soffit joint templet, are applied at B I and A H respectively. In the same manner the third rule is applied at C J and the bottom of its narrow channel reduced to receive the lower edge of this twist rule. Care should be exercised in applying the twist rules that their upper edges are always in the same plane and that the upper edge of the parallel rule is in this plane, all the rules, moreover, should be normal to this plane Any number of twist rules may be thus applied. Ordinarily, a single pair of one parallel and one twist rule will be enough. The balance of the bedding surface may be reduced to the bottom surfaces of the grooves thus cut by applying a straight edge to them on lines parallel to A B and to B C.

Having thus determined the bedding surface the extradosal curve H I J may

Fig. 19

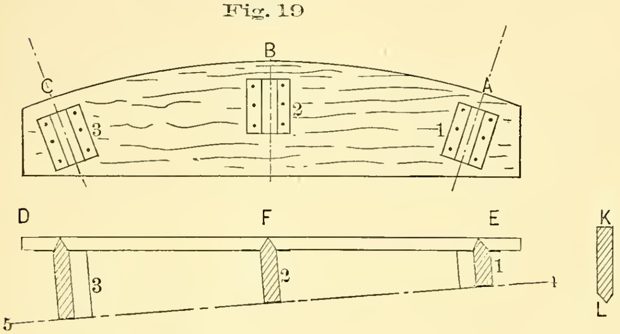


Fig. 20

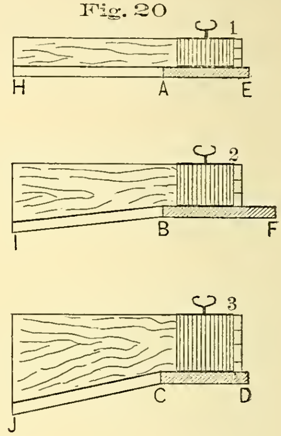
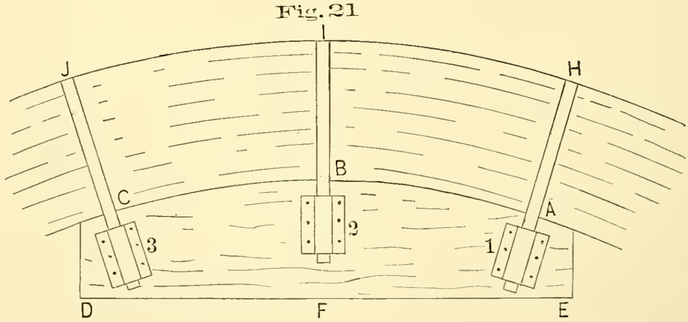


Fig. 21



be drawn upon it parallel to and distant the depth of the arch I B, Fig. 19, from the intradosal curve A B C.

51. The ordinary method of making these bedding surfaces of the voussoirs is: 1st, lay off and sink the soffit course joint A B C. Then the extradosal curve H I J is worked on the rough surface of the stone, and the parallel A H and the twist B I rule are applied normal to the curve A B C, until the upper edges are in the same plane. Then the twist rule C J is similarly applied. Thus used the rules have no arm over the soffit joint templet in the iron straps, as in Figs. 19, they were intended. All voussoirs in a given oblique arch have the same warp, and therefore those that are warped the wrong way cannot be used. This fact should be noted, all oblique arches here given have been *left handed* oblique arches, and the parallel and twist rules have been applied accordingly. When the oblique arch is right handed the order is reversed in their application.

52. We will now proceed to the method of working the warped soffit surfaces of the voussoirs. In Fig. 22, let 5 6 7 8 be the plan, and 5′ 6′ 7′ 8′ the development of the intrados of a voussoir, so

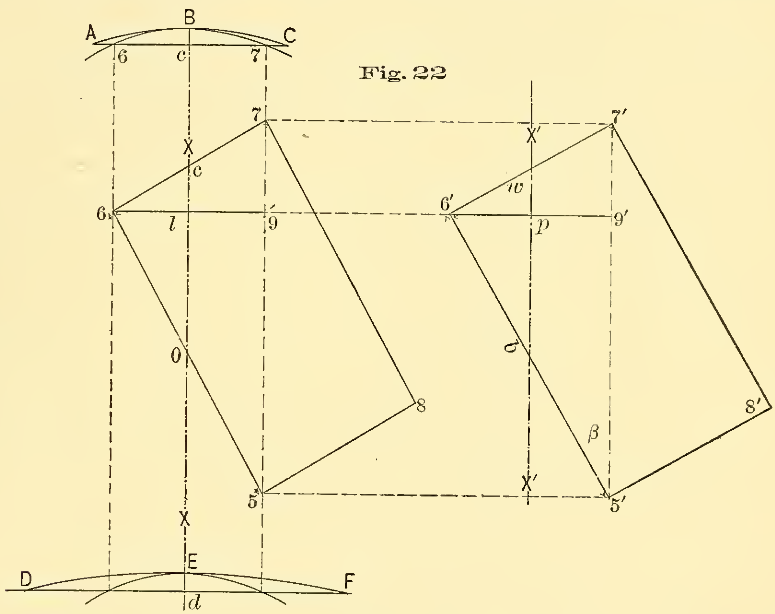


Fig. 22

20 and 21. Obviously this method of reducing these surfaces is attended with uncertain results, and that the method described in the last article is far superior to it. The method there described is true and exact, giving to all these surfaces the same warp or twist, a condition that should always be maintained, and for this reason the method of Article 50 should always be used.

51. Care should be exercised that the warp is worked in the right direction. Nor should we be deluded by the supposition that if the voussoirs are warped the wrong way, they can be used in the other end of the arch from that for which that the axis X X — X′ X′ passes through the middle points of the joints 5 6 — 5′6′, and 6 7 — 6′7′, and let the curves 6 B 7 and 5 E 6 immediately above and below 5 6 7 8 each be circular arcs of the right section of the intrados. In the development the heading joint 6′7′ is perpendicular to coursing joint 5′6′ at 6′, therefore these two joints are normal to one another at the point of their intersection 6 — 6′, and also to the element which is common to the course helicoid and to the heading helicoid at 6 — 6′.

The actual lineal curves of the coursing joints 5 6 — 5′6′ and of the heading joints 6 7 — 6′7′, or their elliptical aproximates can be determined by the methods of Article 10. When regarded as arcs of the circle, their curvature may be thus obtained from Fig. 22. By construction the points 5 and 7 in the plan are in a line parallel to X X. Through 5 6 and 7 draw lines parallel to X X, producing the points 5 and 6 into the arc 5 E 6 and the points 6 and 7 into the arc 6 B 7. Draw 6 9 perpendicular to $x x$ to 9 in 5 7. Then 6 9 is equal to the chords 6 7 and 6 5 of the circular arc 6 B 7 and 5 E 6. Produce the chords 6 7 and 5 6 beyond this arc, and make A c and c C equal to 6 X or X 7, and make D d and d E equal to 6 0 or 0 5. Then A B C will be the circular curve of the heading joints 6 7—6′ 7′, and D E F will be that of the coursing joint 5 6—5′ 6′. Their middle ordi-

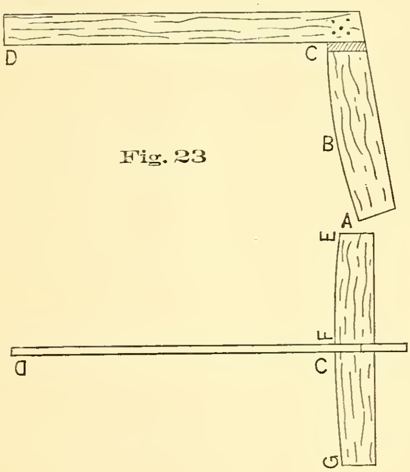


Fig. 23

nates are the same as those of the arcs 6 B 7 and 5 E 6, or both equal to B C or E D. It should be noted that while A B C and D E F are approximate values of, the chords A c C, and D d E are the actual chords of the true heading and coursing joint curves..

53. The radii of these circular approximate curves are thus obtained. Let p be the length of each of the arcs 6 B 7 and 6 E 5 or 6 9 in the development; l their chords or 6 9 in the plan; b the breadth 5′ 6′, and w the width 6′ 7′ of the soffit development, c the chord A c C, and c' chord D d F; m the middle ordinate B c or E d; R the radius of A B C, and R′ that of D E F. Then for the given width w the axis X′X′ will pass through the middle points of w and b,

when $$b=\frac{w}{\text{tang. }\beta} \quad (19)$$

or $$p=w \cos.\beta=b \sin.\beta \quad (20)$$

whence we have

$$l=2\,r \sin.\tfrac{1}{2}\left(\frac{p}{\pi\,r}.180°\right)=2\,r \sin.\left(\frac{p}{\pi r}.90°\right) \quad (21)$$

$$m=r-\cos.\left(\frac{p}{\pi r}.90°\right) \quad (22)$$

in the triangle 6 7 9, $67=c$, $69=l$, and $79=7'9'=w \sin.\beta$,

or $$c^2=l^2+(w \sin.\beta)^2 \quad (23)$$

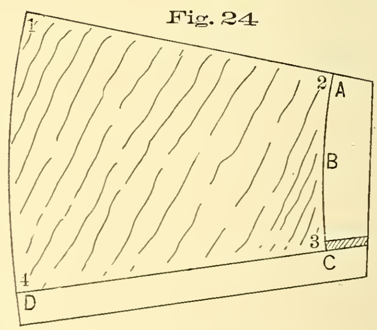
but $$\frac{c^2}{4m}=2\,\mathrm{R}-m \quad \therefore \mathrm{R}=\frac{c^2}{8w}-\tfrac{1}{2}m \quad (24)$$

and in the triangle 5 6 9, $56=c'$, $6\,9=l$, and $5\,9=b \cos.\beta$,

or $$(c')^2=l^2+(b \cos.\beta)^2 \quad (25)$$

and $$\mathrm{R}'=\frac{c'^2}{8w}-\tfrac{1}{2}m \quad (26)$$

Fig. 24



54. Fig. 23 is the side view and plan of the templet for the soffit face of the voussoir, or simply of the soffit face templet. The blade A B C is of the exact length and curvature of the soffit heading joint of the voussoir, and is permanently attached to the stock, so that its edge C D is normal to the curve ABC at C, and blade E F G is also normal to the stock C D at C, and its curved edge G F E is the curve of the soffit coursing joint.

55. The soffit face templet is thus applied. After the first coursing bed has been worked as described in article 50, apply the stock to it and work off the soffit face of the stone until the curve E F G coincides with the soffit coursing joint line already worked on the coursing bed,

at the same time the curve A B C is applied, and the voussoir soffit surface will be worked throughout its entire length. Then on the soffit face so worked, lay off a line parallel to its coursing joint, already obtained, and distant from it a distance equal to the curve A B C of the soffit face templet for the second coursing joint. Then the soffit face of the voussoir is determined.

56. The soffit face templet is then reversed. Its curve A B C is applied to the warped soffit and its curve E F G to the second coursing joint just obtained, and the second coursing bed is worked to the stock C D. Thus let 1 2 3 4 (Fig. 24) be the end view of a voussoir whose upper coursing bed 1 2 and soffit face 2 3 has been worked, the soffit face templet is shown applied to work the second coursing bed 3 4. The extradosal coursing joint on this second bed can be obtained in the same manner it was on the first bed, and then the back of the stone can be worked off, and the whole voussoir will be worked.

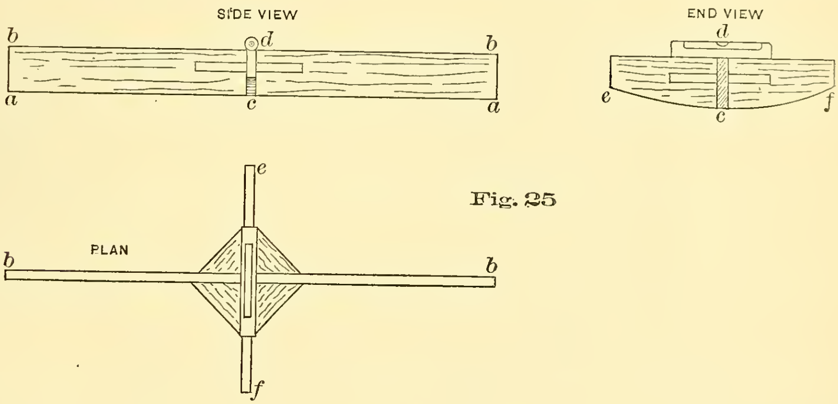


Fig. 25

ANOTHER METHOD OF WORKING THE VOUSSOIRS.

57. First work in one bed of the stone a convenient portion of the soffit cylindrical surface. This may be done by cutting into it the drafts of the arcs of 2 right sections of the soffit, and then working the face to these drafts and on lines normal to these sections. This may be done with the templet shown in Fig. 25. The two arms *a a b b* and *d e c f* are permanently secured to one another so that the parallel edges *a a* and *b b* and the plane of the arm *a a b b* are at right angles to the plane of the arm *d e c f*. The lower edges of the two arms coincide at their point of intersection, and the curve *e c f* is a circular arc of the soffit right section.

A line drawn on a cylindrical surface normal to the right section of this surface is a straight line parallel with axis, or in other words, it is an element of the cylindrical surface. If, therefore, two drafts be cut in the face of the stone to receive the lower edges of this templet, the straight draft will be an element of the cylindrical surface of which the curved draft is a right section, and if either arm be raised over its draft without departing from its plane, and the stone be worked off to receive the sweep of the other arm of the templet, the surface thus obtained will be of the soffit cylindrical surface. If the circular arm extends sufficiently on either side of the straight edge to sweep the entire soffit of a voussoir, the templet may be confined to the single movement of the arm *a a b b* over its straight draft, and this arm may be maintained within a single plane in this movement by a spirit bubble on the upper edge of *d e c f*. In working this cylindrical surface care should be taken that the straight draft should be cut deep enough that the sweep of the circular arm shall be entirely within the body of the stone. Otherwise the voussoir soffit may be deficient.

Through any convenient point A, Fig. 26, of a cylindrical surface thus worked draw an element A E. If 1 2 be the straight draft line over which the arm *a a b b* of the templet (Fig. 25) moved to determine this surface, A E is determined by drawing a line through A parallel to 1 2.

Let A′ B′ C′ D′, Fig. 27, be the soffit development of any voussoir and let a templet of card, lead, zinc, sheet iron or other flexible material be cut exactly to its pattern, with any convenient hole *a* cut through it to show the coincidence of the line A E, Fig. 26, with it. Then apply A′ and line A′ E′ of the templet with A and A E, Fig. 26. Curve the templet exactly to coincide throughout with the worked surface (Fig. 26), and trace on the soffit edges of the voussoir as shown by dotted lines.

58. The templet, shown in Fig. 28, is the same as Fig. 25, except the spirit level is removed and the arm *f g* is added to it. This arm is permanently attached to and is in the same plane as the circular arm *d e c f*, and its inner edge *f g* is normal to the circular arc *e c f*. The coursing beds of the voussoirs are worked to this templet. The arms *a a b b* and *d e c f* are applied to the soffit, care being always taken that the edge *a a* always coincides with an element of the cylindrical surface. In working the bed at A D the templet is applied to the soffit and the point *f* is moved along the joint A D and the stone below is worked off to receive the arm *f g*. To work the bed below B C the templet is reversed, the point *f* moves along B C and the coursing bed below B C is worked off to receive the arm *f g*. The edge *f g*, in application, is normal to the heading joints and to the coursing joints of the soffit when the point *f* is at A, B and C the line *f g* at such points is therefore at the intersection of the heading surfaces and of the coursing beds when so applied. If, therefore, the templet be applied at A and the direction of *f g*

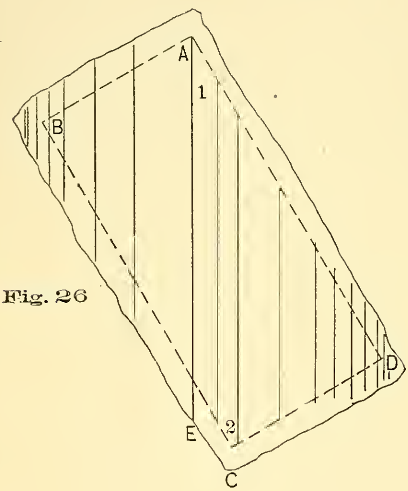


Fig. 26

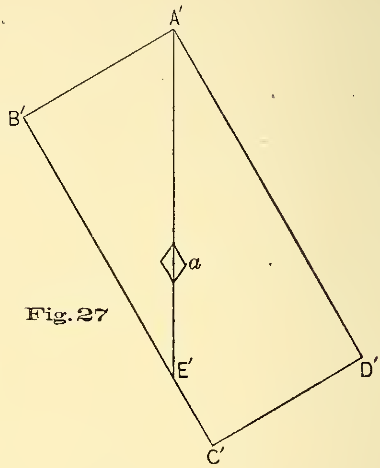


Fig. 27

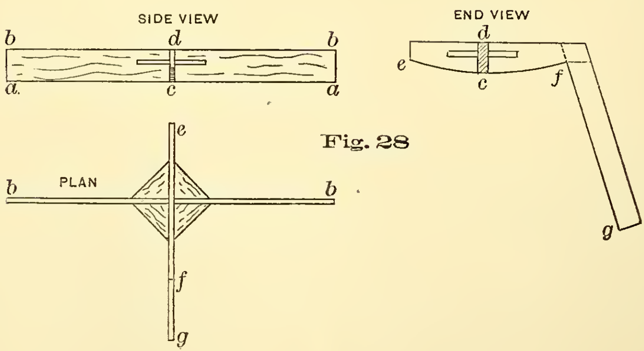


Fig. 28

marked on the coursing bed below A D and then at B and the direction of fg worked on the bed below B C, the heading surface is determined and can be worked to the two lines thus determined and to the heading joint A B. In like manner work off the heading surface at C D.

This process has the great advantage of determining all the joints and surfaces of a voussoir with great exactness. It, however, requires great care in application, simple as is its theory. Care should be exercised, 1st, in working the soffit to true cylindrical surfaces; and 2d, in working the coursing beds for the soffit, that the templet be so applied that the lower edge of the straight edge arm always coincides with an element of the soffit.

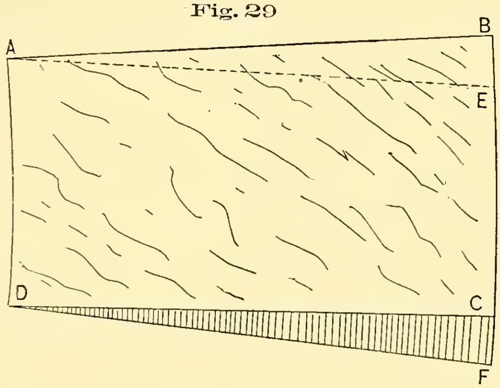
INCREASED COST OF WARPED SURFACES.

59. No exact rules can be given for the percentage of the waste of material in working voussoirs to helicoidal warped surfaces over that of working them to straight surfaces in right arches. For besides the diameter and obliquity of the arches this percentage is dependent upon the three dimensions of the voussoirs.

If we consider an oblique arch of ordinary diameter, but of an unusually sharp angle of obliquity, the per cent. of this waste and cost of working will, of course, be unusual. Let an oblique arch of 30 feet diameter, and of 40° obliquity be such a case, and we will suppose the arch to be 2.50 feet deep $\theta=50°$. The right semi-circumference or $\pi r=47.17$ and from eqs. (11), (13) and (14) $\beta=37°-11\frac{1}{3}'$ $\beta'=41°-31'$ and G S, Fig. 16, 59.165. Let 45 be the convenient number of voussoirs for the face of the arch, then the length of the bedding joint will be $\frac{59.165}{45}=1.315$ whence for Eq. (24) $R=23.07$. If 3 feet is a convenient soffit length for the voussoirs their extradosal length will, Eq. (25), be 3.61. Eq. (6) gives $\Phi=37°-11\frac{1}{3}'$ or equal to β and Eqs. (4) and (5) makes the extreme warp to 0.25 or 3″. The middle ordinate of the soffit heading joint is .009, and that of soffit coursing joint is .012. The intradosal width is 1.31 and the extradosal 1.45.

60. Let Fig. 29 be an end view of a helicoidal voussoir. The waste of material will be a wedge C D E or B A F whose width is the length of the voussoir, or if the voussoir be of the warp and dimensions given in Article 56. This waste will be 1.03 cubic feet. The contents of the warped voussoir or its equivalent straight voussoir are 11.33 cubic feet, or the waste of material is less than $8\frac{1}{2}$ per cent., since the contents of the block from which the warped voussoir curve is 12.36 cubic feet.

Fig. 29



Allowing $1.60 @ perch of 16 feet for quarry stone the block for the straight, and warped voussoirs will cost respectively,

	Straight.	Warped.
	$1.13	$1.24
There are $32\frac{1}{2}$ square feet dress surface in each case, which @ 12c. is........................	3.90	3.90
Extra on account of the warp...		50
	$5.03	$5.64

Or the warped voussoirs will cost $12\frac{1}{2}$ per cent. more than the straight ones.

This per cent. in practice would be less than 10 per cent. This comparison has been made on the supposition that the block stone were quarried exactly to the given dimensions in both cases. In practice, however, they are quarried considerably larger than needed. The block stone would probably be of the same dimensions in both cases. Again, our illustration is an unusual one. In an ordinary obique arch the obliquity is much less, and the per cent. of cost would be less than 10 per cent. If the workmen are skilled in the use of the templet they will cut warped voussoirs as rapidly as straight ones, and the skill is soon acquired. The extra cost for templets is insignificant, in work of any magnitude.

SKEW-BACK VOUSSOIR ARCHES.

61. It will be observed by reference to Fig. 17 that the intradosal development of the voussoirs at the spring lines S V and G Q are right angled triangles. Let Fig. 30 be an enlarged cut of one of these triangles. Its spring line length l or C B is obtained by dividing its whole spring line G Q by the number of these triangles upon it. Draw p or A C perpendicular to l, and let the two parts of l thus divided be t and t'. The angle A B C will be equal to β the angle of the intrados, whence we obtain

$w = l \sin. \beta$ (27) $b = l \cos. \beta$ (28)

$p = w \cos. \beta$ $b \sin. \beta$ (29)

$t = w \sin. \beta$ (30) and $t' = b \cos. \beta$ (31)

The triangular extradosal development of these voussoirs are shown in Fig. 18. Any of these spring lines, p being an element of the intrados parallel to the axis of the arch is a straight line, and the corresponding spring line of the extrados is equal to and parallel to p. Their impost surfaces are plane surfaces. If they are constructed without being made part of the course immediately below them, they will crack off at B and C, Fig. 30, and the tendency to move over the impost will be great. But if they are made part of the course below this weakness will be overcome, and the tendency to move over the impost will be abutted by by the rising walls.

62. These skew-back voussoirs arranged as suggested by Article 57, are thus constructed. The coursing bed at A B, Fig. 30, is worked for its length A B the same manner as that of any voussoir in the body of the arch is. Let Fig. 31 be an end view of one of these skewbacks, A C G H being that of the heading surface. The line A H is normal to the soffit coursing joint of the bed just worked, and is therefore determined. Then apply the stock of the soffit face

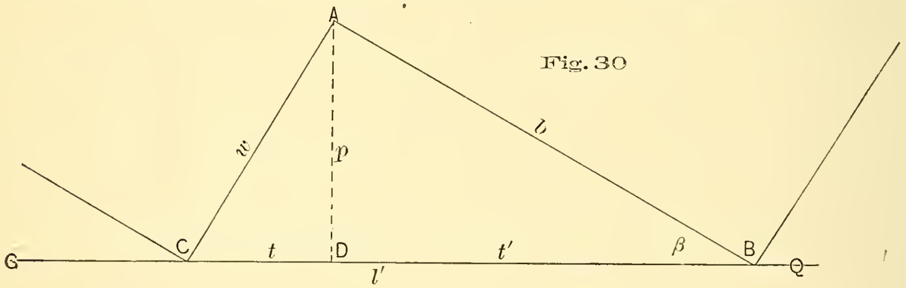


Fig. 30

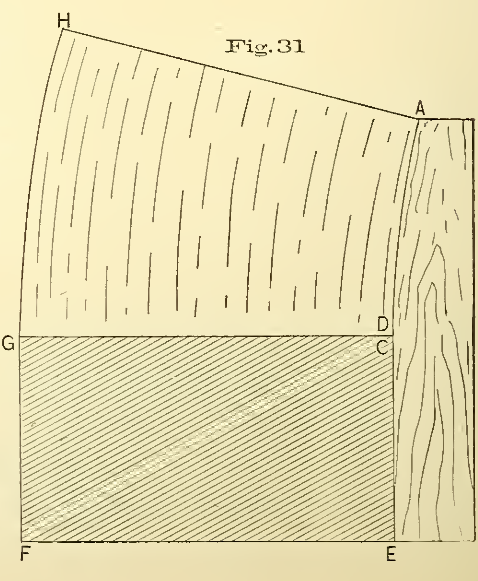


Fig. 31

templet to A H and determine C, Figs. 30 and 32, Fig. 32 being a perspective view of the worked skew-back. Work a straight line C B and let the soffit face templet be applied and the soffit between A B and B C worked. Lay off on C B C D $= t$, Eq. (30), and apply the curve A D of the templet A D E, Fig. 31, to the A D, Fig. 32, and work the line D E in the face of the skew-back. In the templet A D E the curve of the right section of the arch and the straight edge D E departs from a normal to this curve at D in conformity to the latter of the face of the abutment. The line B I, Fig. 32, is an arch face end of the intrados and the extrados between the axis X′X′ and their spring lines S V and R T showing the end curves X′S and X′R and the successive coursing joints of each surface. These end curves should be exactly determined by Eqs. (17) and (18) and the coursing joints by Articles 45 and 46.

Beginning at the axis X′X′ let the corresponding intradosal and extradosal surfaces of the successive courses be numbered 1, 2, 3, 4, &c., and their corresponding coursing joints, 1, 2, 3, 4, &c., as shown.

To determine the angle an end line

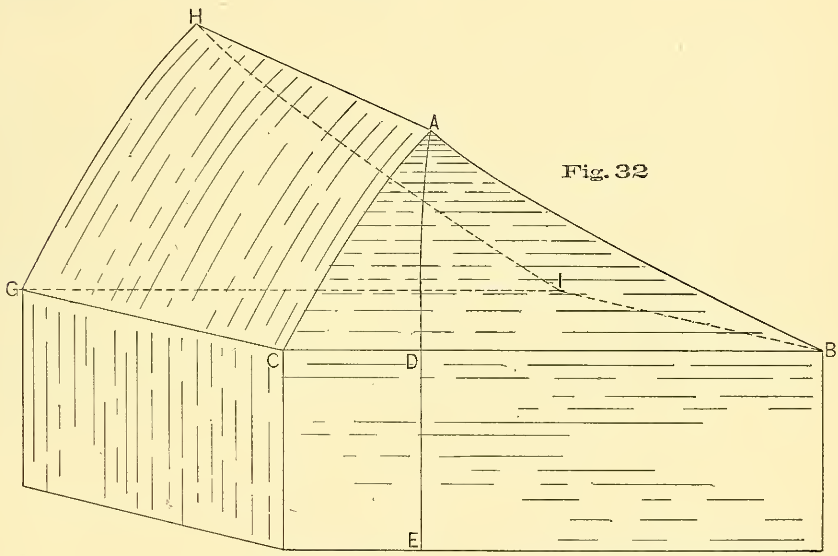


Fig. 32

normal to the curve A B and is determined in working the bed A B I H. Therefore, make C G normal to C B and parallel to I B, and work the heading surface A G by H. The face of the skew-back is then worked off on lines parallel to D E, and the bed parallel to the impost plane B C by I. When the skew-backs are then cut the stone from which they are worked may be quarried without waste of material over that of the voussoir in the body of the arch.

Chapter VI.

METHOD OF WORKING THE RINGSTONES, CENTERING, &C.

Ring Stones.

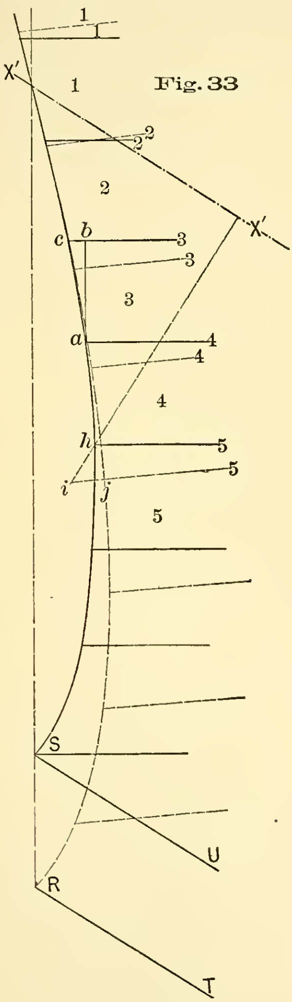
63. Let Fig. 32 be the development of C A of the intrados between any two coursing joints 3 and 4 makes with these joints. Through a, the point of intersection of the joint 4 with the curve X′S, draw $a\,b$ perpendicular to the joint 3. Then if A B C D, Fig. 34, be the soffit of a properly worked voussoir, at any convenient point d draw dce normal to C D or joint 4, which may be readily done with the soffit face templet, Fig. 34. Lay off ef on A B or joint 3 equal to bc, Fig. 33. If then a flexible straight edge be applied to the soffit and df drawn upon it, df will be the proper location of the end line ac, Fig. 34.

All other arch face lines of the soffit may be in a like manner determined.

64. To determine the angle the joint of any coursing bed 5 5, and of the face

of the arch makes with its soffit coursing joint, through h the joint of intersection of the intradosal joint 5 and the end curve $x's$, draw $h\,i$ in a direction perpendicular to the axis $x'x'$, and intersect the extradosal joint 5 at i. By construction h and i are the intradosal and extradosal extremities of the element of the warped

Fig. 33



coursing bed. Therefore $i\,j$ is the distance on the extradosal joint 5 that the point j of the intersection of the extradosal joint 5 and X'R, is from the extradosal extremity of the normal line to the soffit coursing joint 5.

hen if A B and CD, Fig. 35, are respectively the intradosal and extradosal joint 5 5 of the coursing bed A B C D of a properly worked voussoir, apply the soffit face templet to it at any convenient point a, and determine the normal $a\,b$ to the joint A B at a. Lay off on C D, $b\,c$ equal to $i\,j$, Fig. 29, and applying the flexible rule to the coursing bed, draw $c\,a$ from c to a, for the proper location of the arch face joint of the coursing bed 5 5, and for the courses 4 and 5.

In this and the preceding article the entire half of the two curved ends and their coursing joints have been considered, for the convenience of illustration. Such consideration is not always convenient to entertain, but the parts relating to one or more courses may be treated separately by methods that readily suggest themselves.

Fig. 34

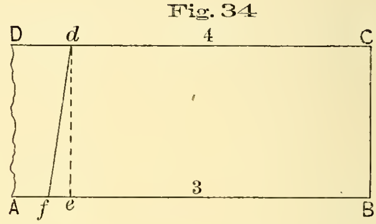
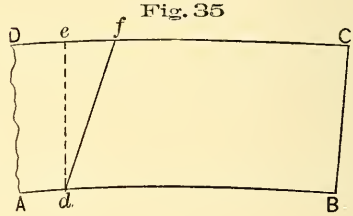


Fig. 35



CENTERING.

65. The centering ribs should be placed in planes parallel to the face of the arch, and, therefore, when so arranged will be eliptical. They are sometimes placed normal to the soffit, or made circular, when, in order to receive the arch under its acute angle, the centering has to be extended beyond the obtuse angle, and there loaded to prevent any movement in the centering when the voussoirs are set near the actual angle. Circular centering should not be employed to receive the voussoirs of an oblique arch. The ribs of the eliptical centering being parallel to the arch face, are in the planes of pressure, are easily maintained and require no more material than is necessary to receive the voussoirs.

66. The sheeting or lagging should be so put on the ribs that it will have an even and smooth surface, and that the centering will be of the exact dimensions to receive the voussoirs. When so prepared the soffit coursing-joints of every course should be carefully and permanently marked upon the sheeting, as a guide for the placement of the voussoirs in the arch. The location of these joints on the centering may be determined from the development of the intrados. As the skew-back stones are generally set before the centering is, no lagging or sheeting will be required on the centering below the intradosal upper courses of the skew-back stones.

SEGMENTAL AND ELLIPTICAL ARCHES.

67. As the same principles are involved in segmental as in full semi-circular right section of a helicoidal oblique arch, no further rules are necessary for their consideration.

As in right segmental arches the axes of oblique segmental arches are in the planes of their imposts or springing surfaces, and their skew-back stones should be constructed accordingly.

Elliptical oblique arches are not recommended, both on account of their structural weakness and the difficulties involved in their construction.

THRUST OF THE ARCH.

68. The thrust of a helicoidal oblique arch being carried to the impost in lines parallel to the face of the arch causes a tendency in the arch to move outward at the acute angle of the arch, which is resisted by the friction of the coursing beds of the voussoirs. This tendency to move increases with the acuteness of the angle of obliquity, and when very acute this tendency should be resisted by properly constructed wing walls. When so constructed these arches may be constructed to any desired angle. It will, however, be a rare case where the angle of obliquity is less than 25°—the limit calculated by John Watson Buck. If he had considered the arch helicoids constructed as recomended in Article 44 the construction would have been more stable, and his limit less than 25°.*

* Helicoidal oblique arches are much more stable than that they are generally supposed to be. During the summer of 1877 the author superintended the construction of two of these arches, of 66 feet cylindrical length, 16 feet right diameter, and of 40° obliquity, each, and though placed under two tracks over which the heaviest railroad traffic passed, these arches, at this time, March, 1886, do not evince the least weakness. No extra precaution was taken to prevent the skew-back stones moving over their beds. A right arch could not have performed the work better or more satisfactorily.

THE CORRELATION OF THE DIFFERENT BRANCHES OF ELEMENTARY MATHEMATICS.

BY R. B. HAYWARD, F. R. S.

From "Nature."

AMONG the permanent acquisitions to mathematical science secured within the last half century, within the limits of those branches with which our Association concerns itself, two (I conceive) stand out as pre-eminent in their far-reaching and all-pervading consequences.

These are the firm establishment as distinct entities of two concepts, which have been fixed for all the future of science in the terms *Energy* and *Vector*, and the development of the groups of ideas and principles which cluster around each.

The term *Energy* indeed, and the great principle of the *Conservation*, or (as I prefer with H. Spencer to call it) *Persistence*, of Energy, the establishment of which will live in the history of science as the great achievement of the central part of the nineteenth century, have a scope far beyond the purely mathematical treatment of dynamics and the allied branches of physical sciences. They, the concept and the principle, have already profoundly modified the views of the physicist as to the natural laws with which he is concerned, and are destined to form the starting-point and firm foundation for all his conquests in the future.

But no less is it true that the conception of energy, while it has naturally arisen out of the higher mathematical treatment of dynamics, has necessitated a very material recasting of that treatment in its most elementary, as well as in its more advanced, stages, if it is to bear any fruitful relation to physical science in general. This recasting of elementary dynamics, if not yet fully and satisfactorily effected in most of the text-books which still remain in use, in which the notion of energy is brought in rather as as the "purple patch" than inwoven into the whole texture of the robe in which the subject is clothed, is yet, thanks pre-eminently to the teaching of Maxwell, Thomson and Tait, and Clifford, in a fair way for being accomplished.

The influence of the conception of energy is, however, as regards mathematics, rather an influence from without than one from within its peculiar domain.

That which is strictly mathematical in the treatment of any science is not its subject-matter, but the *form* in which that subject-matter must from its nature be expressed. Mathematics, as such, is in fact *a formal* (may I not say *the* formal?) science, concerning itself with the particular matter only so far as that matter necessitates a particular form for its expression. Hence the recurrence of the same formulæ and mathematically the same propositions in different branches of science, so that, to take elementary instances, a proposition in geometry may be read off as a proposition in statics by substituting forces for lines, or the formula which determines the speed of the center of mass of two masses having different speeds is also that which determines the temperature resulting from the mixture of two masses of different temperatures.

To this *formal*, or essentially mathematical, part of the exact sciences belongs the conception of a *Vector*, or rather the group of conceptions which cluster around that term. The term itself was introduced by Hamilton in connection with his grand theory of quaternions about forty years since, but the idea had been already firmly grasped and developed so as to afford a complete explanation of the imaginary ($\sqrt{-1}$) of ordinary algebra within the twenty years preceding that epoch. In fact in the year 1845 I myself enjoyed the privilege, as a young student, of attending lectures of De Morgan on this subject, which he afterwards developed in his treatise on "Double Algebra," published in 1849. I think, however, that we may conveniently date from the introduction of "*Vector*," which is now the accepted term for any magnitude which besides numerical quantity or intensity has a definite direction in space, the definitive acquisition of this concept with all its consequences to the settled territory of mathematical science. The calculus of quaternions indeed, or that part of it which was truly original and due to the genius of Hamilton alone, involving the conceptions of the products and quotients of vectors in three-dimensional space, is doubtless beyond the range of what now can be, or within the near future is likely to be, regarded as elementary mathematics; but the notions of vector addition and subtraction and their consequences in geometry and mechanics ought assuredly to be considered as within that range, as ought also, for a complete view of ordinary algebra, vector products and quotients in one plane.

If we inquire in what manner we should expect the idea of a Vector and its attendant ideas to affect our elementary teaching, I think the answer would be that it would naturally lead to a different grouping, or arrangement in order, of the various branches taught. It would lead us to group them not according to their subject matter—arithmetic and algebra, the sciences of number, particular and general; geometry, the science of space; trigonometry, in one aspect treating space and number in combination, in another as a development of algebra; statics, dealing with forces in equilibrium; dynamics, with forces producing motion; and so on—but according to their *form*, as dependent on the nature of the magnitudes dealt with. One-dimensional magnitudes, that is, magnitudes defined by one element only, whether such as are completely defined by one element, or more complex magnitudes regarded for the moment in respect of one of their elements only, would naturally form the first stage, with subdivisions according as the treatment is purely *quantitative* or *metric*, or *scalar*, that is, metric with the addition of the notion of sign or sense. Then would follow two-dimensional magnitudes, or magnitudes defined by two elements, treated with respect to both elements in subdivisions *metric* and *scalar* as in the first stage, and also finally as complete *Vectors*.

If we further inquire how far these notions have in fact affected our elementary text-books, I think we shall find that the extent to which they have done so is very small. A comparison of the text-books of the present day (I speak of them in the gross, not forgetting that there are some important exceptions) with those that were current at the time when my own mathematical studies began, an interval of some forty years, produces the impression of likeness rather than that of contrast. Changes, which are welcome improvements, have doubtless been made in matters of detail, and in various ways the paths have been smoothed for the student; but the general treatment is essentially the same, and shows very little sign of independent thought, informed by more extended views, having been exercised with regard to the old traditional modes of presenting the subject as a whole.

The algebra, for instance, of our ordinary text-books is (if I may venture to give it a nickname which every brother Johnian at any rate will understand) *heptadiabolic*,* or that whose highest outcome, in the mind of the pupil who has studied it, is the solution (so called) of a hard equation or equation problem little more in fact than a series of rules of operation, which skilfully used (and how many fail to attain even this amount of skill) will solve a few puzzles at the end, but very barren of any intellectual result in the way of mental training:—an algebra in which the interpretation of negative results and the use of the negative sign as a sign of affection has been ignored, or so lightly dwelt on, that the notion of the signs + and — as appropriately expressing opposite senses along a line, has to be elaborately explained as almost a new idea in commencing trigonometry; and further, an algebra which, as Prof. Chrystal has observed in his address to the British Association, is useless as an instrument for application to co-ordinate geometry, so that the student has at this stage practically to study the subject again, and only then obtains something of a true notion of what algebra really is.

With the foregoing general considerations as a guide, I will now examine in some detail the correlation or affiliation of the several branches of elementary mathematics to which they seem to lead.

Mathematics naturally begins by treating magnitudes with reference to the single element of quantity. The answers to the simple questions, How many? How much? How much greater? How many times greater? lead up to the arithmetic of abstract and concrete number, and the doctrines of ratio and proportion, and the development of these with the use of the signs +, —, &c., as signs of the elementary operations, and letters to denote numbers or ratios, naturally leads to generalised arithmetic or arithmetical algebra. At this stage $a-b$, where b is greater than a, is an impossible quantity, and a negative quantity has by itself no meaning. In this earliest stage the magnitudes dealt with are either pure numbers or concrete one-dimensional magnitudes, value, time, length, weight, &c., whose measurements are assumed as known. There are few magnitudes which are metric or quantitative *only*, but all magnitudes have quantitative relations which may be regarded apart from their other relations, and so may be the matter or subject of arithmetic, if they are such that their quantity can be estimated definitely or measured. Purely metric magnitudes are such as can be conceived to be reduced in quantity down to zero or annihilated, but of which the negative is inconceivable, so that at zero the process must stop. Such are many magnitudes that are measured by integral numbers—as population, numbers of an army or a flock, a pile of shot, &c., or continuous magnitudes, such as mass, energy, quantity of heat or light, the moisture of the atmosphere, the saltness of water, &c. But there is a far larger class of magni-

* The allusion is to a paper which used to be set at the annual May Examinations at St. John's College, Cambridge, consisting of seven very hard equations and equation problems, familiarly known as the "seven devils." As a test of a certain kind of skill in algebraical operation and of ingenuity and clear-headedness it was not without considerable value, but it tended to produce false notions of algebra in its relations to mathematics generally.

tudes, of which it is true that not only the opposite or negative can be conceived, but that they cannot be fully treated without regard to such opposite. For these, reduction to zero, or annihilation, is only a stage in passing from the magnitude to its opposite, *e. g.* time after and time before a given epoch, lengths forward and backward along a line, receipts and payments, gain and loss, and so forth. The consideration of such magnitudes at once leads to the scalar subdivision of the one-dimensional stage. In this, magnitudes which are themselves purely scalar, or the scalar elements of more complex magnitudes, are alone considered. But to the quantitative element is now superadded the notion of sign or sense, appropriately denoted by the signs + and −, which, without ceasing to be signs of operation, are now regarded also as signs of affection. The introduction of this notion leads at once to scalar algebra, in which $a-b$, where b is greater than a, is no longer an impossible quantity, and a negative result has a definite meaning, so long as the magnitudes dealt with are not purely metric. The step from arithmetical to scalar algebra, though very simple and almost insensibly made, should, I think, be much more distinctly emphasized in our teaching and our text-books than is usually the case. Exercises in metric and scalar readings of the same simple expressions should be frequent, and negative results, whenever they occur, examined and shown to be impossible only if the magnitude in the question is purely metric, but interpretable if it is scalar. Thus the idea would be gradually evolved that the impossibles or imaginaries of algebra are so in a purely relative sense and with regard to the particular subject-matter treated of, and it would become readily conceivable that the remaining impossible quantity $a + b\sqrt{-1}$, to which form scalar algebra, working on the basis of its laws of combination, would show that all expressions may be reduced, may be completely interpretable when ultra-scalar magnitudes form the subject of investigation.

Passing now to the consideration of special magnitudes and how far their discussion can be carried in the one-dimensional stage, I think we shall arrive at some important practical results.

The scalar element of space is length measured forwards or backwards along a line, and the resulting geometry is the simple geometry of points on the same line. Starting from the definition that—AB is BA, the fundamental proposition is that AB + BC = AC, whatever be the positions of A, B, C on the line, and this with a few simple consequences completes all that is necessary to be considered in linear geometry.

Combine with this the notion of time, and the science of linear or scalar kinematics emerges. This includes the measurement of the motion of a point along a given line by the scalar magnitudes, *speed** and *acceleration*, and the discussion of different kinds of linear motion, uniform and uniformly accelerated, and so the laws of falling bodies. When the notion of a variable rate became firmly grasped, the investigation might be extended to some simple cases of variable acceleration without any large demand on algebraical skill, and so the fundamental notions of the fluxional or differential calculus and some idea of its scope and aim be attained.

Introduce now the notions of force and mass and the axioms of force or motion as contained in Newton's laws, and the science of linear or scalar dynamics results. If we drop for an instant the notion of time, or rather of *change in time*, we have linear statics, which consists of little more than the single proposition—the "tug-of-war" proposition—that the resultant of any number of forces along the same line is their scalar sum. Linear kinetics, however, covers a wide field—the relations of force, mass and acceleration, their measures and their applications to simple cases of linear motion; the time integral of force, momentum; the space integral, work; energy, kinetic and potential; the relations of force applied to resistance overcome in simple machines working steadily; impulsive actions in collisions and explosions; and other simple developments—would here be studied in their simplest forms apart from any greater mathematical difficulties than arithmetic and very rudimentary algebra, and yet

* The term *speed* has been happily appropriated for the scalar element of velocity. A corresponding term is wanted for the scalar element of acceleration; no better word than *quickening* suggests itself to me.

involving almost every truly dynamical principle needed for the highest problems in dynamics. Here, with perhaps a few applications to other branches of physics, the range of the one-dimensional stage ends.

Proceeding next to two-dimensional magnitudes, we commence of course with elementary plane geometry, in which the propositions, which are not purely descriptive, deal with the magnitudes considered in purely metric relations.

The introduction of the notion of sense for lines and angles, denoted by the signs + and —, leads in one direction to elementary trigonometry, and in another to co-ordinate geometry.

Kinematics is now extended to motion in two dimensions, and this should lead at once to the notion of velocity, accelertion, &c., as vector magnitudes, and with this the general notion of a vector and vector addition. In dynamics force emerges as a vector, and the composition of forces regarded as the addition of vectors lays the foundation of statics, or the relations of forces independent of the element of time, to be developed on the one side with the aid of pure geometry and graphical methods, on the other by the application of trigonometry. This is naturally succeeded by uniplanar kinetics, developed more or less fully till it extends to regions beyond the range of elementary mathematics. Algebra will have been carried on *pari passu* to meet the requirements of the special subjects, but will still remain scalar with its impossible of uninterpreted symbols.

The next step is to complete the algebra of vectors in one plane. The notion of a vector and vector addition will already have been grasped and will need only some further application and development, but the extension of the notion of multiplication to vectors in one plane at once leads to the already familiar algebra, but with wider meaning and without impossible quantities or uninterpretable symbols. The immediate result is a complete trigonometry, of which De Moivre's theorem, now completely intelligible and not a mere formula, forms the basis, and the higher developments of ordinary elementary algebra. It will then appear that ordinary algebra receives its full explanation in vectors limited to one plane, and it will naturally be anticipated that the algebra of vectors in any directions in three-dimensional space will be different from the ordinary algebra, an expectation which will be amply justified by the study of the algebra or calculus of quaternions, the grand discovery of Sir W. R. Hamilton, but to pass on to this would be to pass beyond the limits of what is, in the sense of our Association, elementary mathematics.

If the correlation of the elementary branches of mathematics, which I have now sketched out, is accepted as based on true principles, I cannot doubt but that it will lead to important practical consequences, the development of which I may safely leave in the hands of those who so accept it. There are, however, a few immediate deductions from it, which occur to me as naturally calling for expression before I close this paper.

In the first place I would observe that while I believe the several stages in the foregoing scheme to be natural and such as every teacher would do well to have in his own mind in arranging the course of instruction for his pupils, I do not at all regard it as marking out the exact order to be followed by each individual student. There is room here, still in subordination to the general scheme, for wide variation according to the different requirements of different students. It would in almost all cases, I think, be very unwise that any one of the stages should be completed before the next was commenced. For instance, though the theory of ratio is purely one-dimensional and metric, no one, I suppose, would think of dealing with it otherwise than in the incomplete form sufficient for arithmetic before commencing the study of the simple two-dimensional geometry of Euclid or our own text-book. And, again, how far scalar or linear kinematics and dynamics should be studied (or whether at all) before proceeding further in the two-dimensional stage to trigonometry, &c., is a question which may fairly be answered in different ways according to the different objects aimed at in the study of mathematics by different classes of students.

It appears to me, too, to follow from our scheme that, whatever may be true for the select few who aim at becoming mathematicians, for the great mass of those with whom the great object is, or ought to be, intellectual training, algebra should be studied at first, not as a subject for its own sake, but as an instrument for use in other subjects. I hold that, unless pursued into its higher developments, algebra *per se* is not a valuable instrument of mental training. Can it be said that such algebra as is required (say) at the Previous Examination at Cambridge, a large part of which has had no application for the student in any other subject, is of any value at all proportional to the time it has taken him to acquire it? I think, then, that algebra should be studied piecemeal: first just that small quantity which is necessary for one-dimensional magnitudes treated as scalars; then, when the need was felt from the occurrence of problems requiring more knowledge of algebra, adding more, and so on continually, keeping up the study of algebra concurrently with, and only slightly in advance of, the requirements of the subjects to which it is applied.

Again, our scheme suggests, I think, a definite answer to the question:—What minimum of mathematics is it reasonable to expect every educated man, not professing to be a mathematician, to have acquired?

I think there are few who are satisfied with the answer practically given to this question by our Universities in their first examinations for matriculation or degrees. At Cambridge, the question with reference to the "Little Go" Examination is even now under consideration. I would submit that the subjects included within our one-dimensional scalar stage, together with elementary geometry and statics, treated geometrically, or by graphical methods only, from the two-dimensional, would constitute a far more satisfactory minimum than the present. This would exclude a good deal of the algebra now expected and the trigonometry, but would add linear kinematics and kinetics. The student, who had gone through such a course, would not probably be able to effect any but the simpler algebraical reductions or solve any but the simplest kinds of equations; but he would have gained some notion of what an algebraical formula means as the expression of a law, and be able to deduce from it numerical consequences and to follow out the simpler general results obtainable from it, and he would have acquired a clearer conception and higher appreciation than is common with people otherwise well educated of the part which mathematics plays in its application to the physicial sciences, and with it that sound dynamical basis which is the essential condition of a fruitful study of physics. I feel sure, too, that the consciousness of the student that he was dealing with actual living laws and not with the dry bones of algebraical processes or trigonometrical formulæ leading to no results, and that his mathematical studies were meant to be, and were, more than a mere mental gymnastic, would add life and interest to those studies which would react on the whole of his mental training.

I may note, further, that our scheme seems to give the best answer to the question which has frequently been mooted of late, in our Association as well as elsewhere, whether statics should precede kinetics, or whether it should be treated as a particular case of the more general science. Linear kinematics and kinetics, being one-dimensional and scalar, may well precede the study of statics, which deals with vectors, though not of necessity in the case of one who has attained sufficient knowledge of elementary geometry not to be stopped by mere geometrical difficulties, but vector or uniplanar kinetics, on account of its much greater complexity and its consequent larger demands on mathematical attainments, would in general naturally follow a somewhat detailed study of statics.

I will take this opportunity of making one other remark, which, if it does not directly arise out of the present discussion, is closely akin to it, and that is on the importance of our teaching of the several branches of mathematics being *proleptic*, or looking forward in one stage to what will be required in a higher stage. In definitions, for instance, of two that are equally good for the immediate purpose, that one is to be preferred which will be intelligible and useful when the term defined comes to be extended to higher matter.

Thus I conceive that multiplication should be defined from the outset in such a manner as would make it applicable to a fractional as well as to an integral multiplier. If I explain that to multiply 6 by 5 is to repeat 6 five times and find the aggregate result, my explanation fails when I am asked to multiply 6 by $\frac{3}{4}$; but if I use De Morgan's definition that "multiplication consists in doing with the multiplicand what is done with the unit to form the multiplier," or an explanation of multiplication cast in this form, I have given an explanation equally simple with the former and applicable also to a fractional multiplier.

Again, in the very beginning of arithmetic, which is counting, I maintain that much would be gained if from the first the child were taught to count, not one, two, &c., but *nought*, *nothing*, or *zero*, one, two, three, &c.; and then if, later on, ordinal reckoning were made to accord with this, though here unfortunately language and usage fail to supply the word wanted, for which, for want of a better, I must coin the form *zeroth* (*noughtth* or *nothingth* being out of the question), thus: *zeroth*, first, second, &c. Then the transition to counting below zero by negative numbers would follow at once as by a natural development, when the need for it arose. Thus when it came to the notation of numbers, the place of a digit would properly be reckoned from the units as the *zeroth* place (not the *first*), and would be extended naturally by negative ordinal reckoning downwards, when decimal fractions are introduced.

This leads me to another illustration, which I am also anxious to introduce as a suggestion on its own merits. Prof. Chrystal has complained that to many students even when beginning coordinate geometry the idea of the *order* of a term or an expression is unfamilar. Now it has occurred to me that this is just the word wanted, to replace the five-syllable word "characteristic," which has been used (or perhaps has *not* been used just because it is pentasyllabic) to express the distance of any digit of a number in order from the unit's digit. Let us speak of the unit's digit as of the order 0; the tens, hundreds, &c., digits of the orders 1, 2, &c.; and the tenths, hundredths, &c., of the orders $-1, -2$, &c.; and add to this that a number is said to be of the same *order* as that of its highest significant digit, and we have a language not only of the utmost use and importance in decimal arithmetic, but also at once applicable by the most natural extension to an algebraical expression arranged according to the powers of some letter or letters, while it would enable us conveniently to express in language numbers which transcend our ordinary numerical vocabulary, so that, for instance, 51×10^{12} might be read as 53 of the 12th order, and 53×10^{-12} as 53 of the -12th order, and so on.

In conclusion I will only add that, if in this paper I have in any parts expressed myself somewhat dogmatically, I have done so in the hope of challenging discussion, and only claim the acceptance of the views which I have tried to express *distinctly*, if *briefly*, in the event of discussion resulting in a verdict in their favor.

CONCRETE.*

By JOHN SLATER, B.A., F.R.I.B.A.

From "The Building News."

I HAVE to-night to ask your attention to the means to be adopted for rendering buildings stable, and securing good foundations. This question of foundation is, perhaps, the most essential of any with which persons connected with buildings have to deal, for if the foundation be faulty, the superstructure, even if it should stand, will certainly suffer. It will be totally useless for the architect to design, or for the deft fingers of the mason to elaborate, the most delicate window-tracery, the most graceful piers and columns, the most stately towers and domes; or for the artist to enrich these creations with the most brilliant

* A lecture delivered at Carpenters' Hall on Wednesday night, March 17.

efforts of his genius, unless the edifice be founded so that no cracks or settlements occur to deface the decorations. In some localities, as for instance, where rock crops up close to the surface, a natural foundation is obtainable, which cannot be improved upon; but in the majority of cases, and especially in London and its neighborhood, it is almost impossible to find a good natural foundation without digging to a depth that is practically out of the question, on the ground of expense. Hence it is necessary to form artificial foundations, and the material principally used for these is concrete. Although the use of concrete as a building material is of comparatively recent date in this country, it was known and extensively used by many of the nations of antiquity. There is ground for thinking that the Greeks were not unacquainted with its use, especially in the Italian colonies of Magna Græcia; and as far distant as Mexico, in many of those curious pyramidal buildings which are the remains of an unknown civilization, concrete foundations have been discovered. But when we come to those grand old builders, the Romans, who were, *par excellence*, the scientific constructors and engineers of ancient times, we find that they used concrete to an extent with which nothing that has as yet been done in modern times can compare. One reason for this was that the Romans found ready to their hand the best materials that exist in the whole world for making good concrete—viz., the travertine limestone, the pozzolana, which is a fine sandy earth of volcanic origin, and a beautiful clean, sharp sand. The use of concrete by the Romans dates back as far as the time of the Kings—*i.e.*, anterior to 509, B. C.; and no less than five kinds of concrete walls are described by Prof. Middleton, who has recently devoted a great deal of careful attention to the methods of construction of the Romans. In addition to using concrete for foundations, they used it without any facing for walls, which were constructed very nearly as described in Mr. Tall's or Mr. Drake's patents, which were taken out a few years ago. Wooden posts were fixed in the ground about 3ft. apart, and boards were nailed horizontally to the posts, and then the intermediate space was filled in with concrete in a semi-fluid state, and as soon as this had set, the boards were moved one stage higher. Thus the concrete formed one perfectly solid mass, and some of these early Roman walls are so solid and hard still that quite recently it has been found necessary to destroy them with dynamite in the course of improvements that have been made. Even when the Roman walls appear to be of brick or marble, this is in every case a mere facing or veneer, and the core of the wall is of concrete. They also largely used this material in constructing very extensive vaults, for supporting upper floors, staircases, ranges of seats, &c. Concrete also formed the basis of all Roman roads; in the early examples the blocks of stone laid on the concrete were much more closely jointed than was the case afterwards. There can be no doubt that the lasting nature of the Roman concrete was due, in addition to the excellent materials, to the careful way in which it was made, and I shall have to refer again to the method of making concrete adopted by the Romans. The French have been very great users of concrete, or *béton*, as it is there called, since the year 1820, and the material has been used in enormous blocks in docks at Toulon, Marseilles, and other places, and in the construction of the Mole at Algiers, and the breakwater at Cherbourg. In this country concrete was employed in very early times, as, for instance, in the foundations of Westminster Abbey, and in the older portions of the sub-structure of St. Paul's; but its use died out, and for a long while the only method adopted for making stable artificial foundations in bad soils was pile-driving. Although Mr. Semple, of Dublin, in 1776, suggested the use of a mixture of sand, gravel and quicklime for structural purposes, it was not till the beginning of this century that concrete was recognized as a building material. Colonel Pasley says that the first use of concrete for foundations was by Mr. Smirke at the Millbank Penitentiary in 1817, and there is a story that the discovery, or rather re-discovery of the fact that lime would combine with gravel and form a sort of artificial stone was a pure accident, owing to the upsetting of a barge-load of lime during the erection of Waterloo Bridge, when it was found that the loose gravelly bed of the river had been rendered hard and compact by the action of the lime. Now, what is concrete? It may be defined as an artificial stone composed of a mixture of hard materials, such as ballast, flints, stone chippings, broken bricks, pottery, or iron slag, called the "aggregate," and a cementitious material called the "matrix," thoroughly combined, together with a sufficient quantity of water. The value of the concrete depends almost entirely upon the quality of the cementitious material, whether lime or cement, and it is most important that you should clearly understand the difference in the properties of various kinds of lime. I must make a short digression here in order to describe them. You are, of course, all aware that lime is produced by burning limestones, and upon the constituents of the limestone depends the quality of the lime. First, there are the rich limes produced from stones which are perfectly pure carbonate of lime—such as the upper and middle chalk formations and white statuary marble. Lime made from these stones is commonly called chalk-lime, and is much used for mortar and concrete in country districts where chalk is plentiful. This lime, when mixed with water, commences to slake, as it is called—*i.e.*, it swells, hisses, give off hot vapor, and falls into powder; and if it be then mixed with water, it will always remain of the same consistency, and never harden at all; and as it is soluble in fresh water, mortar made of chalk lime should never be used for external work, as the action of the weather will soon render the joints quite soft, and anyone who has been present during the pulling down of buildings, the mortar of which was composed of chalk lime, will have noticed how easily the bricks are separated, and what a large amount of dust comes from the demolition. Then come the poor limes, made from the argillaceous or clayey limestones, which contain, in addition to the carbonate of lime, various foreign substances, chiefly silica and alumina, and often a small quantity of oxide of iron. The existence of a small quantity of these foreign substances—as in the Dorking, Halling, and Merstham limestones—causes the lime made from them to show much less violent action when slaked, and enables it to set after slaking, but not under water. Next come the blue lias limestones, which contain a greater quantity of silica and alumina, and produce what is called hydraulic limes, which will set and continue to harden under water; and after these come the so-called natural cement stones found in the London clay formations at Harwich, Sheppey and the Isle of Wight, or in parts of Yorkshire, in the clays of the oolitic series. These contain even more silica and alumina, and from them used to be manufactured the Medina and Roman cements which had the power of hardening under water very quickly. These cements enjoyed a high reputation for many years, but they are now almost entirely superseded by the artificial cements of which Portland is the type. You may take it roughly that rich limes contain over 90 per cent. of carbonate of lime; greystone limes, such as Dorking, about 80 per cent.; blue lias from 66 to 70 per cent., and cements 40 to 50 per cent. When it was a well-ascertained fact that for building purposes lime obtained from the limestones containing a considerable proportion of argillaceous earth was the best, the idea began to gain ground that an artificial cement could be manufactured by mixing chalk with various kinds of clay and calcining the mixture. The patent granted for the manufacture of an artificial cement of this kind, called Portland cement, from its resemblance when set to Portland stone, was taken out by a Mr. Aspden in 1824, who describes himself as of Leeds, in the county of York, bricklayer; but the manufacture was not placed on a really scientific basis till Colonel Pasley carried out his elaborate series of experiments during the years 1826 to 1836. As so often happens with scientific discoveries, it appears to have been by pure accident that he discovered, after many failures, the superlatively good qualities of the alluvial clay or mud of the lower basins of the Thames and the Medway. This clay, which has been deposited in the tidal waters of these rivers, contains exactly the right proportions of silica and alumina for combining with the chalk. It would take too long to describe in detail the manufacture of Portland cement; but, briefly, it is this: the chalk and clay in the proportion, as a a rule, of about 70 per cent. of the former to 30 per cent. of the latter (though these proportions vary with the nature of the chalk), are ground under rollers and intimately mixed together with a great quantity of water until the mixture is of the consistency of thin paste, which is allowed to settle, the water is drawn off, and the residue is left to dry. This is then cut out in lumps and taken to the kilns, where it is burnt at a high temperature, and it is very important that the whole of the mixture should be thoroughly burnt. The effect of the burning is to drive off all the carbonic-acid gas, and to leave the mixture in the form of clinkers. These are then carefully ground to a powder under millstones, to such a degree of fineness that it will all pass through the meshes of a sieve having 625 holes to a square inch. The weight of the ground cement should be as nearly as possible 1 cwt. per striked bushel, and the specific gravity 3.00. The essential difference between lime and cement is that lime slakes with the addition of water, while cement does not; lime powder, after slaking, will not set if mixed up with water, unless sand be added to it, while cement will set at once, and equally well in the water and the air. The property of setting quickly, and setting under water, makes Portland cement of the greatest value, and its use for concrete is extending every day. Now, with regard to the aggregate, this may consist of ballast, stone chippings, broken bricks, &c., but the latter should never form the whole substance of the aggregate, and care should be taken that the pieces are not too large. In the case of ballast, it is most important that it should be clean and free from any admixture of loam or earthy substances. And there is one other point to be remembered, which is, that the concrete will be much stronger for the admixture of a small quantity of sharp sand, which will fill up the interstices between the pebbles, &c., and will make a much more solid mass of the whole. Having thus described the materials of which concrete is composed, I now come to the mixing process, and this is a matter which is far too often neglected. We all know the good old rule-of-thumb way in which ordinary builders' laborers mix up the concrete: a heap of ballast and broken bricks is piled up, a certain, or rather very uncertain, quantity of lime is poured out on it from a sack; then water is added according to the discretion of the mixer, and the mass is quickly turned over and wheeled or shot into the trench; and a very superficial examination is often sufficient to show numerous nodules of unslaked lime after it has been thrown in. Now, this is a most unscientific and improper way of preparing concrete; the great essential is that the lime should all be perfectly slaked during the mixing of the concrete before it is thrown into the trench, and that exact proportions should be maintained. For ordinary foundation purposes, if what is called stone lime be used, two measures should be prepared, the cubical contents of the one being four times that of the other. The large measure should be filled with ordinary ballast, and turned out on a boarded platform; to this should be added a small measure full of sand, and then a small measure full of lime; this will give the proportion of five parts ballast and sand and one of lime, and if this be well mixed and turned over after the water is added, which should be done gradually and in small quantities, it will make a very good concrete for ordinary purposes. If the ballast and sand before the admixture of the lime amount to a cubic yard, it will be found that about 30 gallons of water will be required to mix it thoroughly. This mixture should be then wheeled and thrown into the trenches, *not* from a great height, as used to be considered essential, for, if so, the heavier particles tend to fall to the bottom first, and the mixture will not be so well amalgamated, levelled and rammed. The French method of making concrete, or *béton*, which is almost exactly the same as that adopted by the old Romans, is undoubtedly superior to ours. They invariably mix up the lime and sand to form good mortar *first*, and then mix in the pebbles with it. A heap of good stiff mortar is first prepared, with a moderately hydraulic lime and sharp sand; a barrowfull of pebbles, which have been washed, are then spread out on a platform; over it is spread a barrowfull of mortar;

then a second barrowfull of stones, and and then another of mortar, and the whole is turned over with spades, and dragged backwards and forwards with rakes till the pebbles have become thoroughly enveloped in the mortar, and the whole mass is then thrown into the trenches. An extra precaution against deterioration of the concrete by contact with loamy earth is adopted in the best work by covering the bottom of the trench with a thin layer of sharp sand. The washing of the ballast is an excellent thing, as it tends to clear it from any earthy particles that may have become mixed with it. There can be no doubt that this is a far more scientific method of making concrete than the former. If the mortar is well made you get the pebbles more thoroughly amalgamated, and you insure that the lime shall be thoroughly slaked before the concrete is spread; but it is also more expensive, and I should not consider it necessary to use this method in ordinary cases. But where the soil is very wet, or in any case where the stability of the foundations is of very great importance, I should always recommend the use of cement concrete. With ordinary care in mixing this, supposing the materials are of good quality, you know you can rely upon its setting quickly, and forming a perfectly solid foundation, and you need be under no apprehension of having it spoilt by the inroad of water. The cost is more than that of lime concrete; but not so much more as the difference in cost of lime and cement, because you can use less cement proportionally. Six parts, of ballast, one of sand, and one of Portland cement will make a concrete good enough for almost anything in the way of foundations. Care should be taken that not too much water is used. Faraday, the eminent chemist, said that in the production of concrete the great thing was the discreet and accurate use of water. If too much be used, it will wash the cement away from the particles of the mass before it has time to become thorougly indurated. If the trench in which the concrete is to be spread is not too deep—that is, not above 18 in.—my own opinion is that you will get a harder and more solid mass by filling it up at once to the full thickness, and not putting the concrete in in layers; but if you have to put the concrete 5ft. thick, it must, of course, go in layers. In any case, it will be much improved by being well rammed after levelling. In such a material as concrete there must be a number of minute air spaces. You can see them with the naked eye in concrete that has set, and the act of ramming will drive out much of the interstitial air, and make the particles of the mixture more compact; and the denser such a material is, the stronger it is. Numerous experiments have been made to ascertain the loss of bulk in making concrete. Professor Hayter Lewis found that 27 cubic feet of Thames ballast, mixed with 4½ cubic feet of lime, and 40 gal. of water, made exactly one cubic yard of concrete, and, in some tests made by the Royal Engineers, it was found that 27 cubic feet of broken stones, 9 cubic feet of sand, 4½ cubic feet of Portland cement, and 25 gal. of water, exactly made a cubic yard. The difference between the two experiments may be accounted for entirely by the presence of the sand in the latter case, because the probability is that if a measure containing a cubic yard were filled with broken stones or ballast, it would still hold 8 or 9 cubic feet of fine, sharp sand because the pebbles would not lie close. It is sometimes stated that concrete expands after being mixed. If it does, it is because it has been improperly mixed, and any expansion that takes place after mixing can only cause some disintegration to take place. Hitherto I have spoken of concrete as used for foundations only; but there are many other purposes for which the material can be employed. I suppose it is not much more than twenty years ago that, building materials and labor being at a very high price, and by no means of very high quality, the idea began to gain ground that concrete might be used for the walls of buildings. I have already alluded to the fact that the Romans used it for these purposes, and that, too, although they only had lime, whereas we have Portland cement. But the mixing of the pozzolana, which I have previously mentioned, with the lime gave it many of the characteristics of a cement. The Italian architect, Palladio, writing 300 years ago, gives a very good account of the Roman method of wall construction. He says: "The ancients used to make walls called 'reimpiuta'—*i.e.*, filled up with ragged stones—which is also called coffer-work, taking planks and planting them edgewise in two rows, distant from one another the thickness of the walls, and filling the space between them with cement, stones of all sorts, earth and mortar mingled together, and so on from course to course." This method of using concrete for walls is called monolithic, the concrete being simply poured in a semi-fluid state into the position required, to which it is confined by boards, and it sets in that position, so that the whole of the wall is one compact homogeneous mass. Another method is to form slabs of concrete by casting it in moulds, and allowing it to set there, and the slabs are then taken out of the moulds and carried to the place required, and used in the ordinary way, just like bricks or stone. The former system, if only ordinary care be taken, makes undoubtedly the strongest work, as there are no joints, either vertical or horizontal, and, moreover, no skilled labor is required in this construction, ordinary laborers being able to mix the ingredients and fill in as required. Several systems of apparatus have been invented for confining the concrete to the requisite thickness of wall and for shifting the moulding boards from one stage to another, and many of these are of a somewhat complicated character; but it is very doubtful if any material advantage is gained over the simple plan of nailing the boards to upright posts and filling in between. Walls thus constructed are really stronger than brickwork, drier, and more cheaply built; but great care must be taken in the preparation of the concrete: the cement must be of the best; the aggregate must be broken to the proper size, and the whole thoroughly well mixed. If these precautions are taken, the thickness of the walls may be about 20 per cent. less than with brick. The Metropolitan Board of Works, after a long deliberation, have at length announced their intention of sanctioning the use of concrete as a building material for walls in London, and place the following restrictions on its use—viz, that the proportions shall be one part of cement, two of sand, and three of coarse materials, which may be ballast, gravel, broken bricks or stone, or furnace clinkers; but the coarser materials are to be broken small enough to go through a 2 in. ring. The walls are to be of the same thickness as brick walls, and to be carried up between parallel frames, and the district surveyors are to see that the regulations are properly carried out. I think these regulations too strict as to the thickness of the walls, and as to the proportion of cement, particularly as extensive ranges of buildings have been put up in Southwark where the cement was gauged eight to one. I rather pity the district surveyors in their work of supervision; but the Board seem to have missed the most important point of all—viz., the quality of the cement—and they certainly ought to give their officers power to test this, for, as I have pointed out, serious consequences will ensue if this be not of the best kind. The second, or block system, has, however, some advantages: no particular building apparatus is required; any imperfections in the concrete can be discovered before it is used; the blocks can be made of any required section and of any size, and permanent tints can be given to the blocks by mixing various mineral coloring matters with the aggregate in the moulds. But for laying these blocks, just as much skilled labor is required as is the case with bricks and stone, and, of course, mortar and cement must be used to bed the blocks in; in fact, this is merely artificial blocks of stone instead of natural ones; but this artificial stone is really concrete, and as such it possesses virtues which may be sought in vain in any of the natural building stones, and therefore no lecture on concrete would be complete without a reference to the artificial concrete blocks which are very extensively used at the present time. I believe the first artificial stone which was used in this country was Ransome's, which was patented in 1844 or 1845. This consisted of a mixture of sand, silicate of soda, powdered flints, and a little clay, which was worked up to the consistency of putty, pressed into moulds, dried and burnt, and this burning, in my judgment, takes the material out of the category of concrete stones. Some years later, however, Mr. Ransome found that by dipping the moulded mixture into a bath of chloride of calcium the burning could be dispensed with, and a series of experiments made in 1861 by Professor Frankland showed most conclusively that Ransome's patent concrete stone when only a fortnight old was equal to the best of the natural stones. Soon after Mr. Ransome's first patent, in 1847, a Mr. Buckwell obtained a patent for "Granitic brescia stone," which, I believe, was used in 1851 in the Hyde Park Exhibition. This wase ssentially a concrete, as it consisted of fragments of suitable stone, broken into small pieces and mixed with cement, with a small quantity of water, not more than enough to bring it to a damp state. This was put into a mould and powerfully compressed with a percussive action, and more of the materials added, until the requisite thickness of block was obtained. The block was thus rendered very dense and compact, and this artificial stone was used for water-tanks, than which no severer test can be applied of the qualities of an artificial stone. At the present day the artificial stone which is most used is the well-known Victoria stone, the patent for which was originally obtained by a Mr. Highton. The aggregate of which this stone is composed is ground Leicestershire syenite, a species of granite containing horn-blende instead of mica, and lacking quartz, which is thoroughly washed, so that no earthy particles remain, and an ingenious machine has been patented for doing the washing business. After being washed, the aggregate is carefully mixed with a certain quantity of Portland cement of the very best quality, and is placed in iron-lined wooden moulds, which are filled to the top, but no pressure is applied; after the concrete is set it is taken from the moulds and placed in a bath of liquid silicate of soda, and after ten days' immersion, the block becomes so thoroughly impregnated with silica that nothing but the strongest acids will free it again. The stone thus becomes intensely hard, and quite impervious to weather action—in fact, its hardness increases with time. This property makes it invaluable for copings, sills, paving, &c., and it has another advantage over ordinary stone—that heads and sills can be cast in as long lengths as can be deired, thus avoiding joints. It is used also for sinks and other such purposes. The silica used in the manufacture of this stone is obtained from the Farnham stone found under the Surrey chalk beds, and is boiled in coppers with caustic soda. One of the most enterprising modern pioneers in concrete building was the late Mr. W. H. Lascelles, of Bunhill row, who was a most sanguine believer in the future of this material. Mr. Lascelles actually built cottages, which were not only habitable, but comfortable, the walls of which were only $1\frac{1}{2}$ in. thick, formed of slabs of cement concrete, the outer side cast in imitation of brick or tiles, and the inner side left rough for plastering. These very thin walls appear to have kept out the weather perfectly, but moisture condensed on the inner face, so Mr. Lascelles improved upon his original idea by having a double casing of slabs with a cavity between. He also formed floors of concrete, window-frames and roofs; but the latter did not turn out very successful, as there was always a certain amount of shrinkage. This system did away almost entirely with the use of wood, and consequently the houses so built were as near being fireproof as they could be got. Mr. Lascelles' concrete is composed of four parts of powdered coke and one part of cement mixed together in a mill, with a small quantity of water, and cast in moulds without pressure, and by mixing metallic oxides in the form of powder with the cement, the concrete is colored any desired tint. Very excellent specimens of mullioned windows, chimney caps, head and sills, strings, copings, panels, and over-mantels are made in this material, and are largely used as a substitute for stone, and it is much cheaper than stone; but I am bound to say I have seen cases where the color has not been retained as it ought to be, and I am informed that this is caused by the workmen giving the slabs a top dressing of colored cement after they come out of the moulds. Of course this should never be done, as the color should really penetrate some depth into the mass of concrete. For standing a London damp and smoky atmosphere there can be no doubt of the great superiority of this concrete to almost any natural stone. Messrs. Lascelles also make a very good wall on what is termed Potter's patent. In this, a casing of concrete slabs, of which one face is fair, is put up, and ordinary concrete filled in between just as in the way I described in the wooden framework; but as the slabs are intended to remain, they are formed with a key, so that when the core of concrete sets, it is quite impossible for the skin of slabs to move. Among the numerous purposes for which this material is used may be mentioned silos, water-tanks, sewer-pipes, columns, &c. It would occupy too much time were I to attempt a description of all the methods of concrete construction that have been invented, such as Tall's, Drake's and others; but the most recent of them—the system patented by Messrs. West—has various novel features about it which deserve attention. This, like Potter's system, is a slab construction filled in with rough concrete; but the form of the slabs is ingeniously arranged, so that no temporary tie or external support is required during building. The slab itself is made of concrete cast in a mould, so that on one side is a finished face, plain or ornamental, as the case may be, and on the other a sunk panel about half the thickness of the slab itself, with its edges undercut, so that when in position, and the mass of semiliquid concrete is poured in, the slabs are securely keyed to the general mass. Dovetail mortise-holes are also formed in the top and bottom edges of the slabs, in order that when laid they may be kept in their proper place by simply pouring into these holes some quick-setting cement. There is also a narrow groove along the edges of the slab which, when filled with cement, acts as a joggle joint, keeping the slabs together. An inner and outer casing of slabs is thus set up, and the plastic concrete poured in, filling up the sunk panels and making with the slabs a perfectly solid wall. For openings, jams are moulded, having recesses, or dovetailed holes, into which the fluid concrete may penetrate, so that they can be thus keyed to the general mass of the wall. The slabs are made either rectangular or hexagonal on plan, and as they are all cast in a mould, there is, of course, not the slightest difficulty in arranging for circular work, splayed angles, or anything of that kind. There has always been considerable difficulty in arranging for moulded or enriched stringcourses or projections, with concrete, and this difficulty is proposed to be overcome by casting the moulding first and then applying it to the slabs while they are in a plastic state, the moulding thus becoming part of the slab, which is then fixed in the required position. The moulds for casting these slabs are made of metal and lined with indiarubber. Similar slabs can be moulded with curves for constructing domes, and ceiling slabs can be made with rebates, so that they can be supported on iron joists or girders. This system of concrete building is certainly the most scientific and the most complete that has yet been invented, and I have no doubt whatever that a building thus erected would be perfectly dry and very strong; but I am somewhat disposed to think that the system is a little too complicated to be cheap, as the labor required for properly setting the slabs in place and cementing them together would nearly equal that required for a stone wall. The inventors have, however, shown so much skill in maturing their design and providing for all difficulties, that it is quite possible they may soon be able to point to actual works carried out on their principle, and to give accurate details of cost, which I am not able to do now. A very ingenious traveling scaffold and concrete elevator have also been invented by Messrs. West, which obviate the necessity of erecting a scaffold all round the work, and require no putlog holes to be left; and undoubtedly some such arrangement as this has been a great desideratum as an auxiliary to concrete construction. There can be little doubt that this system of concrete building would be of most material use in the construction of farm buildings, cottages, &c., in country districts far removed from railways, as the slabs are light and portable, and the material for the filling can generally be obtained on the spot. For paving purposes, concrete is, of course, excellently adapted; but it is very difficult to get ordinary workmen to lay a concrete floor properly. What they like is to lay the concrete and let it get hard, and then finish off the top with a thin coating of neat cement. This looks very well when it is first done; but sooner or later the thin coating begins to flake off or crack, and looks very bad. The proper way is to break up the materials of the concrete to a small size, and then, in laying it, to trowel it off at the top as smooth as possible, so that it is all one mass and no layers exist. Portland cement should always be used, and if ordinary care be taken, there is no reason why a laborer should not lay an excellent concrete floor. There are many patents for concrete paving, of which I may mention Drake's granitic concrete and Macleod's granitic, which has been largely used in the North of England for warehouses, stables, &c. It is not cast in blocks, but laid *in situ*, and it can be made to take somewhat of a polish if desired. This forms an extremely hard, impermeable pavement, and it looks very well; but I really believe the whole secret of the excellence of these patent systems of paving lies in the careful manipulation of the materials and the sparing use of water. I may state here that for engine-beds concrete is, in many respects, far superior to stone, as it is not liable to chip and crack, and it is very much less expensive. I now come to the last division of my subject, and that is the use of concrete for vaults, and in fireproof construction. Everyone is acquainted with the fact that an ordinary arch exerts a thrust which has to be counteracted, or it would soon push out its abutments. A concrete arch, however, after it has set, forms a complete homogeneous mass, and exerts only a dead weight on its supports. The Romans were aware of this, and constructed the boldest and most extensive vaults of concrete—as in the Baths of Caracalla, and the House of the Vestals lately excavated. They were careful, moreover, to make the concrete used for these purposes of lighter materials than that employed for walls or pavements. The great dome of the Pantheon was constructed entirely of concrete of varying thickness, and the walls supporting this enormous mass were 20 ft. thick. In the House of the Vestals the whole of one of the upper floors, about 20 ft. span, consisted entirely of a great slab of concrete 14 in. thick, merely supported by corbels projecting from the walls, and in the Baths of Caracalla there are still extensive remains of large concrete vaults. We, in this country, have not yet obtained satisfactory evidence of the safe span and thickness of a concrete vault; but the material is very largely used to form small arches in fireproof floors. It is quite impossible to treat the very important question of fireproof buildings fully at the fag end of a lecture—the subject demands a whole evening to itself; but whatever system of fireproofing be adopted, concrete will prove to be the most important element in it. Whereas, the opinion used to be held that iron girders and columns as supports to a building were sufficient to make it fireproof, we have been taught by sad and costly experience that this is very far indeed from being the case. In the United States and in France they are much more particular than we are in this matter, and, in the former country, it is laid down as an incontrovertible maxim "that no building can be fireproof unless all constructional ironwork be protected," and no better material can be found as a protection than concrete. Stone is utterly valueless in this respect, as it will crack when heated, and give way without any warning whatever. Fox and Barrett's system consists in filling in concrete between wrought-iron joints, the concrete being supported on fillets of wood placed about ½ in. apart, and resting on the bottom flanges of the iron joists, the underside of the wood fillets being plastered. Either the concrete is carried up the requisite height and forms the floor, or if a wooden floor is required, small joists are cut to a dovetail section and imbedded in the concrete, and the floor boards nailed to them. Dennett's system is almost exclusively a concrete construction, consisting of concrete arches supported next the walls on projecting courses, and by hollow iron joists at intermediate points. In this system gypsum is mixed with the Portland cement to form the matrix, as experiments have shown that this substance can be heated to whiteness and then suddenly cooled without being injuriously affected. In Hornblower's system the iron girders are surrounded by cement, and inclosed in a fireclay casing, supporting fireclay arches. Even concrete arches supported on triangular-shaped wooden joists form a floor which is very largely fireproof. If iron columns are used, a temporary wooden casing should be erected round them, leaving a space of about 2 in., which should be entirely filled up with Portland cement concrete, and if a fine face be desired this can easily be obtained by cementing the concrete. Messrs. Lindsay have patented two systems which comprise the use of steel decking, as it is called, and concrete arches, the girders being entirely covered with concrete, both at top and bottom. The concrete used by this firm is very light; it is called pumice concrete, and is composed of washed coke breeze and sand mixed dry and Portland cement of the very best quality. It is, of course, self-evident that if you get sufficient adhesiveness and transverse strength, the lighter the mass of concrete is for upper floors or vaults, the better, as so much less weight is thrown upon the supporting walls or columns. The steel girders for this kind of floor are of peculiar shape, and the system is a novel one, and appears to me likely to prove of great value for buildings of considerable size, where girders are a necessity for supporting upper floors. These girders may be described as truncated, equilateral triangles, set alternately on their bases and their truncated vertices, and riveted together at their sides, forming a series of hollows and elevations. They are constructed of rolled steel about $\frac{1}{2}$ in. in thickness, and their depth need not be much more than half that required for an iron girder. When the weights required to be supported are not very heavy, a combination of these steel girders with ordinary rolled joists can be adopted. The iron joists can be placed about 14 ft. apart, and from the steel skewbacks riveted to the joists, arches of concrete can be turned on centring. There is a possibility with concrete floors that would withstand any ordinary strain, that the sudden fall of anything like a huge iron safe might break through the floor; and in order to avoid any risk of this kind, Mr. Lindsay runs steel wires through the joists the whole length of the floor before the concrete is filled in. These are about 18 in. apart, and are strong enough to hold up any exceptional weight that may by accident come upon the floor. In addition, these steel wires form a sort of nucleus around which the concrete sets. The total weight, girders and all, of these latter floors is considerably less than that of any other system, and they are extraordinarily strong. I have now endeavored to bring before you some of the purposes for which this common material concrete is adapted. Its use is extending daily, and in that extended use lies a danger which it behoves us all to guard against; whether you are employing it for floors, for pavings, for walls, for vaults, for architectural enrichments, or what not, it cannot be too strongly insisted upon, that scamping of every kind must be avoided, that the quality of the Portland cement used in its manufacture must be of the very best, and that no labor in manipulation must be spared, for if inferior materials be used, or carelessness in working, the results are sure to be disastrous, and grave discredit will be thrown upon a most useful building material. The subject is a sternly practical one, and it has been impossible to illustrate it by elaborate and beautiful drawings; but, at least, we can learn one lesson from it, and that is, the great, the incalculable value of thoroughness in all the work which we have to undertake. As I commenced by referring to the Roman builders, so I would conclude by pointing to them again as a model for us. Depend upon it, when they were building the walls of those edifices which are still the wonder of the world, they gave no thought to what posterity would think of them; they simply did their work in the best way they knew of, and spared no pains to make it good; and if we imitate them in this, we shall all, whether architect, builder or artisan, have the satisfaction of feeling that we have done some bit of good work; and although it is not given to us all to be great artists and to "witch the world" with noble buildings, we can at least put our whole heart into everything we undertake and display what has been described as the truest genius—an infinite capacity for taking pains.

The Scotch railways are joining with those of England in the opposition to Mr. Mundella's Railway and Canal Traffic Bill. The principle it embodies of giving power to the Board of Trade to fix rates compulsorily is severely condemned by all in any way connected with railway interests.

THE CHEMICAL TREATMENT OF THE LONDON SEWAGE.

From "The Engineer."

The Metropolitan Board has boldly decided on treating the whole sewage of the metropolis by the chemical process which has been undergoing elaboration under its auspices during the last two years. In the resolution thus arrived at, the Board has the warrant of two reports, signed by Sir F. Abel, Dr. Odling, Dr. Alexander W. Williamson, and Dr. Dupré. These are high authorities; and, although it may be said that three of them were not originally disposed to admit that the Thames was in an offensive condition, yet there is the remarkable fact that one of the four—Dr. Williamson—was himself a member of the Royal Commission presided over by Lord Bramwell. Since that Commission took evidence, the chemical operations at Crossness have doubtless thrown further light on the subject, so as to justify some modification of the views previously entertained. The second, and final, report of the Royal Commission bears the date November 27th, 1884, whereas the first report from the four chemists is dated eleven months later. The interval was one of activity at Crossness, and the Metropolitan Board wished to know whether the process devised by Mr. Dibdin would work satisfactorily. Mr. Dibdin, the Board's chemist, was then using 3.7 grains of lime and 1 grain of protosulphate of iron per gallon of sewage. The chemical referees, if we may so term them, expressed their opinion that the result would be "a very great gain over the discharge of untreated sewage;" and they further declared that the process, apart from the precipitating action, did exert "a distinct purifying effect upon the liquid part of the sewage." On the other hand, they considered that the effluent retained a sufficiently unpleasant oder to prohibit its discharge into the river during warm weather at all states of the tide. Had the report ended here, the verdict would have been a little discouraging; but there was an important supplement. The referees saw reason to believe, from what they had witnessed in the way of experiment, that the addition of manganate of soda and sulphuric acid to the effluent would so far deodorise and purify it as to allow of its being afterwards discharged into the river "at all states of the tide." It was, at the same time, a question whether this supplementary treatment would be necessary in the winter months. In their second report the referees decided that the deodorising process would be unnecessary during a considerable part of the year. For the purpose of deodorising the effluent during warm weather they recommended crude commercial manganate of soda, ranging in quantity between 0·5 grain and 1·5 grain per gallon of effluent, with a proportion of sulphuric acid equal to about one-third of the crude manganate.

The report of the Works Committee of the Metropolitan Board in reference to this subject explains that the evidence given before the Royal Commission was of so conflicting a character, that it was felt nothing short of a prolonged series of experiments on a tolerably large scale, extending over some months, and including day and night, would afford the information necessary before working plans could be drawn up for the erection of plant for the treatment of the whole of the sewage. Thus the Board went seeking for new light, and if the report, which includes Dr. Williamson as a signatory, is to be allowed any weight, we must believe that the Board found the object of its search in the experiments conducted by Mr. Dibdin. But behind the precipitation and the deodorization there was the *bete noir* of the sludge. To purify the sewage was one thing, but to get rid of the sludge was another. Reckoning the daily volume of the sewage at about 150 millions of gallons, the resultant sludge is estimated at 3,000 tons. This, when pressed, is reckoned at 850 tons of cake. It is well that Mr. Dibdin is able to use a comparatively small quantity of chemicals. The lime which he introduces will add about 40 tons per diem to the actual sewage residium, which is considerably less than the bulk which most chemical processes would leave to be dealt with. Still, there is the sludge, and no small quantity either. If some enterprising individual would take the lot, with all its virtues, he might have it for nothing, even though the Board had previously borne the expense of pressing it. The stuff cannot be burnt, for the fumes of its combustion are found to be objectionable, even in the not very savory neighborhood just outside the metropolitan boundary. Digging it into land is not an easy matter. Giving it away to the farmers is not altogether hopeful, considering the depressed state of agriculture. It might be used to raise the level of the low-lying lands bordering on the Thames; but the Board contemplates the contingency of flinging it all into the German Ocean. What effect this would have, it may interest some of the experts to determine. The sludge may feed the fishes, it may create shoals, it may go ashore, or it may happily disappear altogether. Some experience on this point has been gained at New York and Boston, but the London sludge will be on a scale pre-eminently large. We have already dealt with the proposal of Mr. J. Orwell Phillips, who elaborated a plan whereby the Beckton screw colliers would be made available for carrying off the sludge in the form of compressed cakes to be thrown overboard at sea. The Board has since invited designs for ships specially constructed to carry away the sludge, and have received as many as twenty-three designs in response. In respect to other arrangements, the Works Committee state that the contract drawings for the enlargement of the Barking sewage reservoir, and arranging it for precipitation and purification works, are in a forward condition, so that the contracts may be let in the course of the coming summer. The works may be completed and brought into full operation in the summer of 1888. Until then reliance is placed on the deodorising works already provided, and which, it is believed, will prevent any nuisance at the Barking outfall. Throughout the approaching summer nine millions of gallons of sewage are to be precipitated daily at Crossness, the remainder being deodorised until the process of precipitation has been extended to the whole of the southern sewage. With regard to the sludge, so much of it as nobody will accept gratuitously is to be sent in lighters out to sea, both in the liquid and in the cake condition, in order to ascertain the cost and effect of this mode of getting rid of it.

The cost of all these operations is, of course, a serious matter. Yet there is encouragement even in that direction. The capital expenditure for dealing with the sewage at the present outfalls is reckoned at about £750,000. The annual cost, including interest on capital, deprepreciation of plant, wear and tear, and all other expenses, is estimated at £118,000 per annum. When we referred to the subject some time ago, the annual cost was a trifle below this amount, but the first cost, including £131,000 for barges to carry the sludge, was £1,140,000. The Royal Commissioners reckoned that the chemical treatment of the London sewage would cost £200,000 per annum; but in so doing they were aiming at a higher degree of purification than that which is considered necessary by the Metropolitan Board. At Barking and Crossness there is no need to fear any pollution of a drinking supply, and hence a different standard of purity is permissible than would be proper in a part of the stream situated above the intakes of the water companies. Associated with the treatment of the sewage at the outfalls is another operation, which as yet has attracted but little notice. Commencing in July last year, the Board has proceeded to apply manganate of soda and sulphuric acid to the sewage *in transitu*. At more than a dozen stations on the lines of the great intercepting sewers these purifying re-agents have been introduced, the effect being, not to occasion precipitation of the solids, but to deodorise the sewage and prevent the escape of noxious gases from the ventilators. A further advantage consists in the fact that the sewage will arrive at the outfalls in a deodorised condition—a circumstance which, the Works Committee remark, will materially assist in the production of an effluent of a far better character than would otherwise be attainable. The character of the occasional discharge from the storm overflows will also be improved. Anything that can assist the difficult process of sewer ventilation is especially to be valued, and the plan thus commenced by the Metropolitan Board will strike most persons as a happy expedient, the sewage being dealt with before it has time to become putrescent. The principle may be capable of extension, and so long as there is no increase of deposition in the sewers, the deodorising process may simply be limited by the question of cost. If the District Board and Vestries will each, in their own respective localities, imitate the example of the parent Board, the result will be so much the better. Another incident in this history is the extraordinary cheapening in the price of manganate of soda, in consequence of the development in the manufacture of this article by Mr. Dibdin. Owing to the limited supply and great cost of the manganate, Mr. Dibdin undertook to manufacture the article on a large scale. This so far stimulated the action of the manufacturing chemists that they now come into the market with large quantities of manganate of soda; and whereas some time back the price was £40 per ton, and the supply altogether inadequate, the figure has fallen to £11 per ton, and the supply is practically unlimited. The real use of the manganate of soda, in conjunction with sulphuric acid, is the production of permanganic acid. It is represented by the Board that the purifying agency of this compound is such as to render filtration through land unnecessary. This may be called the turning-point of the whole controversy. It is urged in certain quarters that the Board should implicitly observe the recommendations of the Royal Commissioners. But the reply of the Board is that, by means of this cheap and extensive supply of manganate of soda, it is practicable to apply permanganic acid on a scale which provides an equivalent for land filtration. Probably it is to this consideration that we may mainly attribute the approval which Dr. Williamson now accords to the treatment of the sewage at the existing outfalls. According to the available light on the subject at the time when the Royal Commissioners drew up their final conclusions, they advised that if the sewage were chemically treated at Barking and Crossness it should only be as a temporary measure, unless the effluent were subjected to intermittent filtration through a sufficient area of land. If the same result can be produced by chemical means, and at a greatly reduced cost, there is fair ground for the argument that the Board should not be forced to comply with the mere letter of the law, while amply fulfilling its spirit.

It is impossible to look at the plans of the Metropolitan Board, admirable as these may be, without remembering that another project has been brought forward, based on ample details, and possessing many features of merit. Of course we are alluding to the Canvey Island scheme of Mr. Bailey Denton and Lieut.-Colonel Jones. In the last report of the Works Committee of the Metropolitan Board in reference to this subject, the Canvey Island plan is discussed in a manner which seems hardly fair. The report of the Committee states that one element in the plan thus brought forward was that the Board should deliver the whole of the London sewage over to the projectors, accompanied by an annual payment of £110,000. The report goes on to say, "The view taken by your Committee, and also by the Board itself, upon this part of the scheme was that it would not be consistent with the Board's duty to hand over the sewage to be dealt with by other persons in consideration of a very large annual payment, and that the Board could not rid itself of its responsibility in that matter." A reply on this basis was sent to the Home Secretary, through whose department the Canvey Island project was in the first instance forwarded to the Metropolitan Board. The report ought to go on to say that to meet this objection Messrs. Denton and Jones offered to transfer their interest in Canvey Island to the Metropolitan Board, so that the latter body might keep the sewage under its own control, and carry out the plan without further reference to the original promoters. No doubt the Committee's report is correct so far as it goes. The first proposals were rejected for the reason assigned. But why do we hear nothing of the amended offer? As the report stands, the reason given for rejecting the Canvey Island scheme is inconclusive, seeing that it merely refers to a past phase of the question, and makes no allusion to the form which it now assumes, this latter phase being entirely free from the objection urged against the first. It may be very true that in its amended form the project is not such as the Board feels called upon to accept. But due respect to all parties, even to the Board itself, demands that the true reason should be specified. We apprehend that the final objection to the Canvey Island scheme is really its costliness. Here, however, we touch a debated point, Mr. Bailey Denton contending that the plans of the Metropolitan Board will prove more expensive than the project which he has brought forward. The Board has evidently a different view of the case, and if the question is pressed, perhaps we shall hear more on that point. The Works Committee put into their report a statement based on information derived from Sir Joseph Bazalgette, that if the outfalls were removed to Hole Haven, the capital cost would not be less than £3,725,000, while the annual expenditure, including the treatment of the sewage there by precipitation, would be £215,000. As this latter amount is nearly £100,000 more than the annual cost of the scheme which the Works Committee have recommended, and which the Board has adopted, it might be inferred that carrying the outfalls still further on, so as to reach Canvey Island, would exhibit a yet greater excess. A subsidiary topic is that which relates to the proposal of Mr. John Orwell Phillips to carry the sludge out to sea in the Beckton colliers, on their return voyage to the North. The *Times* has complained that no reference to this proposal is to be found in the report of the Works Committee. Had such reference been made, it is to be expected the Committee would have stated that Mr. Phillips' proposal proved to involve a much greater outlay than was anticipated. Here again is a question of estimates, and the Board will justify itself by saying that it has to guard the pockets of the ratepayers, and therefore has to do its work in the cheapest fashion it can devise. Relative cost thus comes under consideration, and if it should yet appear that the Beckton scheme is cheaper than any other for the removal of the sludge, we shall doubtless hear more about it, and we cannot say that we quite despair on that point. At all events, something must be done with the London sewage beyond what has yet been accomplished, and the Metropolitan Board is addressing itself to the task in a manner which shows that it has decided upon a plan which it will carry out without loss of time, unless prevented by some interference from without.

THE CONSERVATION OF ENERGY.*

By S. DIXON, Manchester.

From "Iron."

It is the common experience of all men, but especially of engineers who were constantly engaged in controlling the great forces of nature, that various bodies or disposition of matter, possessed the power of doing work in a greater or lesser degree. It was not his purpose to enter into an examination of the whole of the various forms of energy, but he would take two or three with which they as engineers came most frequently in contact, viz., mechanical energy, heat and electricity. They frequently met nowadays with a steam engine driving a dynamo for producing the electric light, and they had there a fine example of the transformation of energy, embracing three or four of the most prominent forms. They saw, in the first instance, heat conveyed to the engine by the steam and disappearing in large quantities. In the second place, they saw mechanical energy produced in the motion of the various parts of the engine, this being transmitted, it might be, by a strap to a dynamo, and there disappearing. In the third place, they had the production of the electric current, conveyed, it might be, by a wire to a lamp and there disappearing, and the fourth

* Abstract of paper read before the Manchester Association of Engineers, March 14, 1886.

step they had the production of light scattering its energy around by its brilliant piercing rays. They might here note that in all these various forms they never saw one coming into existence without the disappearance of another; they saw heat disappearing and mechanical energy appearing, which on disappearing reappeared in the form of electricity, only to disappear as electricity and reappear as light and heat. They saw, therefore, in this combination a complete cycle of operations commencing with heat and going through two or three transformations to reappear as light and heat. They saw these transformations taking place, but it was not at first sight obvious that it was the same energy which was being transmitted throughout, but if they applied instruments capable of measuring the amount of energy in each form, and making due allowance for the leakage taking place at each stage, they would find that it was precisely the same amount of energy which was passing through the various forms. The great law of the conservation of energy taught them that they could not create energy, and the principle of the dissipation of energy taught them that they could not destroy energy. Yet, during the great transformation which took place, a vast amount of energy became degraded as it were, and rendered useless for the purpose of doing work. When they saw how our various sources of energy were being rapidly used up, he thought they could not but admit that an enormous responsibility rested upon them as engineers not to squander the stores of energy which were practically in their keeping for future generations. He thought there was nothing which they, in this truly wonderful nineteenth century, would so much regret as that the judgment of posterity on this our age should be that we had been so extravagant and wasteful of the great stores of energy that we had fearfully crippled, if not entirely ruined, the prospects of all succeeding ages. Seeing the vast importance of economising our stores of energy, they might possibly ask what had he to suggest in a particular way for improving on the present system, and, in reply, he would say:—1st. Let our engineers fully master the great principles of science, so that they may never be found attempting to set aside some of the inexorable laws of nature. 2d. Let us have a more truly scientific spirit applied to all our work, which carefully measured and estimated everything and took nothing for granted, however plausibly it might be presented. Let them carefully estimate the cause, and honestly measure the effect, and face it openly, no matter how unfavorable the results might be to them. Let them not be content to say that an engine, a machine, or any device whatever, would do a certain amount of work, but that they would be at once able to say how it did it, and how long it took to do it. He would suggest that the absolute efficiency of every engine or machine should be distinctly specified and insisted upon by the purchaser, so that in the struggle now going on only those firms which were really capable of constructing economical and highly efficient engines have any opportunity of survival, and that the construction of antiquated and extravagantly wasteful engines which yet survived should soon become a thing of the past. He would in fact urge measures which should facilitate the rapid survival of the fittest. The cheapness of coal in this country had in some respects been very disadvantageous, having fostered extravagance; but on the Continent, where coal was much dearer, the construction of economical engines had, he did not hesitate to say, been carried to a greater perfection than in this country, for any new device which ensured the most fractional increase of efficiency was at once adopted. He had often noticed, when discussing the peculiarities of their respective engines with continental engineers, that they always prominently spoke of their absolute efficiency in a truly scientific sense, as requiring so many kilogrammes of steam per horse-power (the only true test), whereas he feared that with us it was too often the diameter of the piston and the length of the stroke which absorbed our attention. It was, however, not only in steam engines that a greater application of scientific methods was required; in machine tools the need of improvement existed perhaps even to a greater degree. The long-continued commercial depression and the greatly increasing foreign competition had recently led to considerable searching of heart and examination of the weak members of their organization, and if it had no other, it would have one beneficial effect in compelling engineers to equip themselves in the most efficient manner for the fight. During the palmy days which had now gone for ever, the tendency of engineering firms had undoubtedly been to become fossilized. How many firms could they see to-day, of even large extent, where machines were at work which positively gave one a shudder to contemplate, and which ought long ago to have been put under the steam hammer. They saw some firms holding on to these antiquated tools with the greatest tenacity, whilst young firms were springing up (on the Continent, it might be), and leaving these parental firms heavily handicapped in the struggle. Let them take, for example, such a simple instance as a lathe, which was generally regarded by many firms as being pretty much the same thing all the world over; yet so great was the difference that, with the most modern tool, the same man would be producing 20 feet of $2\frac{1}{2}$-inch shafting per hour, whilst with old ones, to which they still clung so tenaciously, he was scarcely able to produce 20 inches per hour. It was not sufficient now that a lathe should do a certain work, but that it should do it in the least possible time. In the great competitive struggle for the survival of the fittest, they might well draw a lesson from what they saw in the struggle for pre-eminence amongst nationalities. What was the position of the nations with their antiquated armor, and what was their chance in the fight? As engineers they might well ask themselves what chance had those firms with antiquated machinery, and what must naturally be their doom. He was quite sure that there were at the present time many firms with machinery corresponding in antiquity and want of adaptability to the requirments of to-day, which might be fitly compared with the muzzle-loading guns, if not even with the flint-lock age, in weapons of war.

STRENGTH OF WHITE PINE, BRICKS AND STONE.

By PROF. W. A. PIKE.

Journal of the Association of Engineering Societies.

The author gives the results of tests recently made in the testing laboratory of the University of Minnesota. Sticks of thoroughly seasoned white pine were tested for tensile strength. They were dressed to a uniform scantling 12 inches in length, with shoulders on ends to take the pull. In scantling they varied from $\frac{3}{4}$-inch square to $1\frac{3}{8}$ inches by $2\frac{1}{2}$ inches; average specific gravity, 0.66. The average ultimate tensile strength was 7,373 pounds per square inch. It was observed that the longitudinal shearing strength of the ends of the sticks, in resisting the pull, was less than has been generally given. The ends had a shearing-area of 45 square inches; but it was necessary to spike and clamp the ends in order to prevent splitting. Thirty-five tests were made of white pinewood for resistance to compression, in which the pieces varied from 1-inch cubes to pieces 3 inches square and 54 inches in length. Of those which broke by direct compression, the crushing resistance averaged 5,283 pounds per square inch. One-inch cubes bore 7,800 pounds. Pieces 3 inches square and 54 inches long bore 5,222 pounds per square inch; 24 inches long, 5,038 pounds; and 12 inches long, 5,505 pounds per square inch. Of those which failed by a combination of crushing and bending, from 54 inches to 24 inches long, and from 4 by 2 inches to 2 to 1 inch in return, the average actual stress or load was about 3,000 pounds. The author argues from the results that the value of the usual constant in the ordinary formula for the resistance of struts is much too great.

Half bricks, placed between pieces of paste-board, were tested for crushing resistance. St. Louis bricks failed flat-wise under 6,417 pounds per square inch; edge-wise, under 4,080 pounds. Hastings red brick, hard, medium and soft, failed respectively under 2,017 pounds, 2,012 pounds, and 1,748 pounds per square inch.

RANKINE'S THERMODYNAMICS.

By DE VOLSON WOOD, C.E., M.A.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

II.

The expression

$$dQ\frac{d(dU)}{dq}=d\tau\frac{dp}{d\tau}dv=d(dU) \qquad (p)$$

is evidently true for imperfect as well as perfect gases when an actual pressure works over the space dv, for it is simply equivalent to $dpdv$. The next step is a novel one from a mathematical standpoint, for it is equivalent to

$$\frac{d(dU)}{dQ}\int_0^Q dQ=Q\frac{d(dU)}{dQ}=dW,$$

or to

$$\frac{d(dU)}{d\tau}\int_0^\tau d\tau=\tau\frac{d(dU)}{d\tau}=dW, \qquad (q)$$

which operation is equivalent to considering $\frac{d(dU)}{d\tau}$ as independent of τ, or, more generally, as constant during this integration. Here dW is an element of the total work, both external and internal. Now, $\frac{d(dU)}{d\tau}$ is not independent of τ, except for perfect gases. For perfect gases have, equation (a)

$$pv=R\tau$$

hence for v constant we have

$$\frac{dp}{d\tau}=\frac{R}{v}$$

which is independent of τ, and substituted in equation (p) gives

$$\int d\tau\frac{R}{v}dv=\int\frac{R}{v}dvd\tau=\tau\frac{R}{v}dv=pdv$$

in the first of which, there being two independent variables τ and v, the integration may be performed once in regard to either, and when integrated in regard to τ we have the result as given. In the case of a perfect gas, there being no internal work, the external work pdv equals the heat expended. But if the gas be imperfect and represented by equation (k) we have, if v be constant,

$$\frac{dp}{d\tau}=\frac{R}{v}+\frac{a}{\tau^2v^2}$$

and

$$d\tau\frac{dp}{d\tau}dv=\left(\frac{R}{v}+\frac{a}{\tau^2v^2}\right)d\tau dv$$

and Rankine treats this by integrating the $d\tau$ outside the parenthesis, treating the quantity within as constant during the integration, in the case of the transference of enery, giving as a result

$$\tau\left(\frac{R}{v}+\frac{a}{\tau^2v^2}\right)dv$$

for an element of work, both external and internal. If treated according to the ordinary rules of calculus we would have found

$$\left(\frac{R}{v}\tau-\frac{a}{\tau v^2}\right)dv$$

which simply reveres the direct process giving the original expression as it ought and which would reduce finally to

$$pdv$$

which is the value for an element of the external work only. Rankine's deduction of equation (q) from equation (p) is as novel as it is original. It is the point of departure from the ordinary treatment of analysis and appears to be defended chiefly, if not entirely, on physical grounds. It is equivalent to asserting, for physical reasons, that the elementary quantity of energy which may be transferred from a body possessing heat energy to another body for a unit of energy (or temperature) equals the rate of transference of the element per unit of temperature $\left(\frac{dp}{d\tau}\right)dv$ into the absolute temperature, τ, at which the transference is made; and this assumes that each element of temperature produces its proportionate share of the work of transference. In other words, this is a repetition of the second law. Reject Rankine's second law, and this analysis is without foundation. Had this mode of treatment emanated from a mathematician and physicist of less repute, it would doubtless have required independent proof to have secured its acceptance.

One can but admire the genius of a man who has such an insight into the workings of nature and such a command of mathematics, that he can at once express the laws of such working in so direct, simple, and comprehensive a manner as Rankine has done in this case. It is a characteristic of some of his writings that he seized an advanced principle, the mere statement of which more than half solved the problem. But these qualities do not insure immunity against errors in principle or logic. In regard to the latter may be cited his treatment of turbines, in which he presumes to treat a general case, which is in fact only a restricted one; and in regard to the former, Sir William Thomson, in the twentieth lecture on "Molecular Mechanics," says: "I do not think I would like to suggest that Rankine's molecular hypothesis is of very great importance. The title is of more importance than anything else in the work. We cannot find a foundation for a great deal of his mathematical writings, and there is no explanation for this kind of matter." In the case we are considering, however, Rankine arrives at the same result as Thomson, Clausius and other writers. Rankine applies this method to the transference of energy of any kind, in his paper "On the General Transformation of Energy," read January 5th, 1853, and similarly in another paper "On the Mechanical Action of Heat," read January 17th of the same year. These are published in the *Transactions* of the Royal Society of Edinburgh, vol. xx., also in the London *Philosophical Magazine*, and in his Miscellaneous Scientific Papers; but nowhere has he made a more complete solution of the part involving the most refined analysis than in our text. Those who understand his logic need no further statements on this point, but we are not ignorant of the fact that many students find almost an insurmountable difficulty in establishing the "symbolic expression" of the second law. And this is not surprising after the late Clerk-Maxwell, with his bright intellect, considered the law itself as "inscrutable." To such we offer the following considerations in favor of its acceptance:

Its correctness is readily verified in the case of the ideally perfect gas, as already shown, and hence for this case it is rigidly exact.

It is so nearly exact for gases considered perfect, as air, hydrogen, &c., that no error can be detected by experiment, and therefore, must be treated as strictly exact for these gases.

It is correct when the pressure increases directly as the temperature. Thus if p_1 be the increase of pressure for a rise of temperature t_1, then

$$\tau \frac{dp}{d\tau} dv = \tau \frac{p_1}{t_1} dv = pdv.$$

Since $\tau \div p$ will equal $\frac{p_1}{t_1}$. This principle was used by our author in an article in *The Engineer* of June 28th, 1867, in which he sought to explain and illustrate the second law in a simple and popular manner by finding the latent heat of steam. (Miscel. Sc. Papers, p. 432.)

The second law regarded as a statement of the law of efficiency of a perfect heat engine is universally accepted, page 343 of our text. Similarly in regard to Carnot's principle. (*Phil. Mag.*, 1846, p. 313; 1856, 1, p. 215.)

Clausius says: "If the first theorem is called the *Theorem of the Equivalence of Heat and Work*, the second may be naturally called the *Theorem of the Equivalence of Transformation*." (*Phil. Mag.*, 1868, 1, p. 414.)

Its application to imperfect gases gives results that are correct within the limits of errors of observation. On this point we might say considerable, but we simply remark that the formulas which represent imperfect fluids are empirical, and are not only subject to errors, greater or less, but cannot be safely applied much beyond the range of the experiments upon which they are established. For some interesting cases, see articles 255, 256, 257, 258A of our text.

Finally, it may be accepted with confidence, because it has been obtained by different eminent scholars and by independent methods of analysis.

It is an advantage to a student, in attempting to overcome a difficulty, to be assured that the result sought is correct, for then he has only to contend with his own methods, being certain that the difficulty exists within himself. The investigator, however, must push forward and establish himself beyond the boundaries of previous knowledge.

Returning now to the consideration of the subject, we observe that in treating the expression

$$\tau\frac{dp}{d\tau}dv,$$

the process of its generation must be recognized, that is τ is independent of $\frac{dp}{d\tau}$, and hence the latter may be operated upon independently of the former.

At the close of article 241 the author says: "which quantity is known when Q and the law of its variation of d U with Q are known;" in which we have another singular mathematical expression—that of a relation between a finite quantity Q and a differential quantity d U! This needs *interpreting*, and may readily be done by changing the form to the one last given, and the quotation should read "which quantity is known when τ (or Q) and the law of variation of p with τ are known."

Resuming equation (q) we have for the work done *at constant temperature*

$$W=\tau\int\frac{dp}{d\tau}dv \qquad (r)$$

In this expression, W is a function of τ as well as of v, and as $\frac{dp}{d\tau}$ for imperfect fluids cannot be expressed simply in terms of v, the total differential of W will be the sum of the partial differential equations regarded as functions of τ and v. The two partial differential equations are

$$\left(\frac{dW}{dv}\right)=\tau\frac{dp}{d\tau}$$

$$\left(\frac{dW}{d\tau}\right)=\tau\int\frac{d^2p}{d\tau^2}dv \qquad (s)$$

or the total differential may be expressed thus:

$$d.W=\tau\, d.\int\frac{dp}{d\tau}dv \qquad (t)$$

where the dot is used, as by the author, to express the *total* differential. This treatment of equation (r) is similar, in principle, to Lagrange's method known as the *Variation of Parameters*, which here consists in first treating $\frac{dp}{d\tau}$ as independent of τ and dependent upon v in which case the integration may be performed, and the arbitrary constant for which afterwards treated as a function of τ. This method of treating certain differential equations is explained in higher works on the calculus, such as Price's Infinitesimal Calculus, Boole's Differential Equations, and Todhunter's Integral Calculus. It will be observed that these expressions of our author are "symbolic" and as such simply *indicate* the mode of operation in the solution of particular examples. In the case of internal work done at constant temperature, equation (s), written thus:

$$(dW)=\tau\int\frac{d^2p}{d\tau^2}dv.d\tau$$

will be zero, but in other cases the amount of internal work at temperature τ for a change $d\tau$ may be finite, and will be different at different points in the scale of temperature. This principle is involved in that of specific heat to be considered hereafter.

Equation (t) being an expression for the *work* done, both external and internal, by the disappearance of heat for an elementary change of volume and temperature, it remains to find an expression for the quantity of heat producing change of temperature only which will be so much of the heat imparted to the body as is in excess of the work, both internal and external, that has been done by heat. All the heat imparted to a substance above that which disappears in doing *work* makes the substance hotter. Observation shows that the same quantity of heat communicated to equal weights of different substances will not produce the same rise of temperature. Thus, one pound of steam at 300° Fahr., mixed with ten pounds of hydrogen at 40° F. will produce a mixture of two pounds at about 74° F., but the same steam mixed with ten pounds of water at 40° will produce a mixture of two pounds at about 146° F., there being no escape of heat in either case. The thermometric measure is called the *sensible* heat. As seen from the preceding example, the same amount of heat will produce different degrees of sensible heat in different substances. The "total actual heat" defined by Rankine is the sensible heat. The ratio of the quantity of heat which produces an increase of temperature in a unit of weight of any substance to that of the temperature in the same substance is, according to Rankine, constant for all temperatures and pressures (page 307) for a given state of aggregation, and is represented by k. This principle Clausius calls in question, and gives it as his opinion that it is variable, as, for instance, in the case of water. Physical constants, so-called, are rarely, if ever, *strictly* constant, although they are often so treated when they are known to vary, as in the case of gravity for which we use $g=32.2$ except in cases where the problem demands greater refinement, and if they are constant their *exact* value is as rarely found, as in the case of Joule's mechanical equivalent of heat. The real specific heat of substances is constant as defined by Rankine within the limits of errors of observation, and hence must be treated as strictly constant until shown to be otherwise. Granting Rankine's symbolical expression of the second law and his principle of specific heat, his first general equation of thermo-dynamics may be written directly without intermediate analysis. For the heat necessary to increase the temperature an amount $d\tau$ will be

$$d\text{H}=kdt \qquad (u)$$

which being expressed in foot-pounds and added to the heat disappearing in doing work produced by an elementary change of volume and temperature, equation (t), will give the total heat producing both changes simultaneously, or

$$d.\text{H}=kd\tau+\tau d.\int\frac{dp}{d\tau}dv \qquad (\text{A})$$

$$=kd\tau+\tau\int\frac{d^2p}{d\tau^2}dv.d\tau+\tau\frac{dp}{d\tau}dv \qquad (\text{B})$$

which is equation (2) page 312 of the text. Equation (A) may be written

$$d.\text{H}=$$

$$\text{J}k'd\tau+\tau\left(d\tau\frac{d}{d\tau}+dv\frac{d}{dv}\right)\int_{v_1}^{v_2}\frac{dp}{d\tau}dv \qquad (\text{C})$$

as given by our author in the *Philosophical Magazine*, 1856, (2), page 103. In the last equation J is Joule's equivalent and k' the real specific heat compared with water, and $\text{J}k'=k$ is the real dynamical specific heat.

Equation (A) may also be written, as in the text,

$$d.\text{H}=kd\tau+\tau d.\text{F}=\tau d\varphi \qquad (\text{D})$$

where

$$d.\text{F}=\left(\frac{d\text{F}}{d\tau}\right)d\tau+\left(\frac{d\text{F}}{dv}\right)dv$$

and

$$\text{F}=\int_{v_1}^{v_2}\frac{dp}{d\tau}dv$$

The expression for $d.\text{F}$ is written in the above form in one of Rankine's original papers, and in our text this form is implied.

The terms "heat potential," heat "factor," "metabatic function," and "thermodynamic function," used by our author in this connection, remind us of a remark of Sir William Thomson in his twentieth lecture on "Molecular Dynamics" before referred to, where he said, "Rankine was that kind of a genius that his names were of great suggestiveness; but we cannot say that always of the substance."

Clausius writes the partial differential equation

$$d\text{H}=\left(\frac{d\text{H}}{d\tau}\right)d\tau$$

to express the quantity of heat due to an elementary increase of the temperature of a substance, in which if $\left(\frac{d\text{H}}{d\tau}\right)$ be constant it cannot be integrated unless it is a *known* function of τ. If it be constant it may be represented by k as above. Equation (A) can be used in any particular case only so far as the function is continuous, and hence is restricted to that of a constant state of aggregation.

Representing the sum of the coefficients of $d\tau$ in equation (B) by C_v, and dividing through by τ the equation becomes

$$d\varphi=\text{C}_v\frac{d\tau}{\tau}+\frac{dp}{d\tau}dv,$$

which is the form of the general equation given by Clausius when τ and v are the independent variables (equation 21, page 206 of Brown's translation). This equation cannot be integrated unless C_v is either constant or a function of τ, and $\frac{dp}{d\tau}$ also a constant or capable of being expressed as a function of v.

A discussion of equation (B) enables

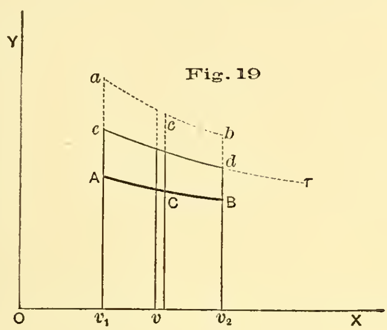
one to see more clearly the meaning of each term.

a. Assume the temperature constant. Then will $d\tau=o$, and the equation becomes

$$dH=\tau_1 \frac{dp}{d\tau}dv$$

$$\therefore H=\tau_1 \int_{v_1}^{v_2} \frac{dp}{d\tau}dv$$

which is a measure of the heat that must be supplied from an external source in



order to maintain the constant temperature τ_1 while the fluid expands from v_1 to v_2, and since all the heat supplied has been transmuted into work, internal as well as external, it is called *the latent heat of expansion* (page 309), or the heat which disappears in doing work. The case is represented graphically by Fig. 19, in which the ordinate vC represents the pressure p, when the volume is Ov, and the ordinate $vc=\tau_1 \frac{dp}{d\tau}$ is such that when multiplied by dv will give an element of work both external and internal, and the integral of the expression between the limits v_2 and v_1 multiplied by τ_1 gives the entire work, $v_1\, v_2\, ba$ done during the expansion. The ordinates to the line AB represent the external pressures for the corresponding volumes.

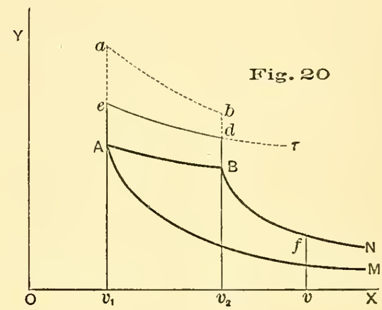
If through A and B respectively the adiabatics AM and BN be drawn, Fig. 20, then will the indefinitely extended area MABN represent the heat communicated to the substance from an external source while doing the external work v_1ABv_2 at constant temperature, as will be shown hereafter, and from this fact it follows that the area between the adiabatics MABN is greater for an imperfect than for a perfect gas, the same external work being done with each substance.

Having the equation of the fluid, the relative height of the line ab may be determined. Thus in the case of carbonic acid gas we have:

$$p=R\frac{\tau}{v}-\frac{a}{v^2\tau}=v_1A \qquad (v)$$

If this gas were perfect, we would have $a=o$, and

$$p=R\frac{\tau}{v}=v_1e,$$



and $e\tau$ would be the isothermal and v_1e the pressure for a perfect gas.

From equation (v) we have:

$$R\frac{\tau}{v}-p=\frac{a}{v^2\tau}=Ae.$$

When τ is constant the term $\frac{a}{v^2\tau}$ decreases as v increases, hence the line of pressures, AB, approaches the isothermal line $e\tau$, and ultimately becomes an asymptote to it.

The ordinate v_1a which represents the pressure involved in doing both external and internal work, will be

$$\tau\frac{dp}{d\tau}=p+\frac{2a}{v^2\tau} \qquad (w)$$

$$\therefore Aa=\tau\frac{dp}{d\tau}-p=\frac{2a}{v^2\tau},$$

so that for this fluid the distance ea above the isothermal equals Ae the distance of the line of external pressures below the isothermal. The line ab will also approach the isothermal and ultimately be an asymptote to it. In an adiabatic expansion the temperature decreases while the volume increases though not at so rapid a rate, and the distance between the isothermal corresponding to any pressure, and the lines of pressures does not diminish so rapidly as in the preceding case.

By means of equations (v) and (w) we may compute both the internal and external work for this gas at constant temperature. For the external work we have by means of equation (v),

$$\int p dv = R\tau \int_{v_1}^{v_2} \frac{dv}{v} - \frac{a}{\tau} \int_{v_1}^{v_2} \frac{dv}{v^2}$$

$$= R\tau \log. \frac{v_2}{v_1} - \frac{a}{\tau}\left(\frac{1}{v_1} - \frac{1}{v_2}\right)$$

which shows that the work performed during the expansion is less at constant temperature for an imperfect than a perfect fluid. It must not be inferred that this result conflicts with the principle taught by the masters of this subject—that the work done by heat is independent of the nature of the working fluid—for the latter principle is restricted to work done in a cycle, while the above analysis applies only to expansion.

For the total work, both external and internal, we have, by the aid of equations (w) and (v),

$$\int_{v_1}^{v_2} \tau \frac{dp}{d\tau} dv = R\tau \int_{v_1}^{v_2} \frac{dv}{v} + \frac{a}{\tau} \int_{v_1}^{v_2} \frac{dv}{v^2}$$

$$= R\tau \log. \frac{v_2}{v_1} + \frac{a}{\tau}\left(\frac{1}{v_1} - \frac{1}{v_2}\right)$$

and the difference between these, or

$$\frac{2a}{\tau}\left(\frac{1}{v_1} - \frac{1}{v_2}\right)$$

gives the internal work.

If $v_2 = \infty$, we have

$$\frac{2a}{\tau v_1}$$

for the total internal work at constant temperature for an infinite expansion, which is finite, while the external would be infinite. The last expression is a function of the temperature and initial volume only.

b. Consider the volume constant.—Then will $dv = o$, and the third term of equation (B) disappears, but the second term will not vanish for the same condition, since dv is there under the integral sign and may be considered in the sense of an integration performed, and the equation becomes

$$dH = k d\tau + \tau \int \frac{d^2p}{d\tau^2} dv . d\tau$$

$$\therefore \frac{dH}{d\tau} = k + \tau \int \frac{d^2p}{d\tau^2} dv = C_v \qquad (x)$$

which is the rate at which heat must be supplied to a pound of the substance per *unit* of temperature, in order to raise the temperature one degree, and hence is called the specific heat at constant volume (v and τ being the independent variables). For a perfect gas the integral part of the expression is zero, hence, by integration,

$$H = k\tau \qquad (y)$$

or the temperature increases directly as the quantity of heat supplied. This reveals no additional truth, but simply reduces the expression back to the assumption made by the author in the case of a perfect gas in a constant state of aggregation. According to Equation (x) the term reprepresenting the real specific heat (or real dynamic specific heat if measured in foot-pounds) will be constant, and the *apparent* specific heat will exceed this by the amount of heat necessary to do the internal work at constant volume.

c. Let there be no transmission of heat and no external work done. Then, in equation (B), will H and $dH = o$, v be constant and $dv = o$, and the equation becomes

$$o = k d\tau + \tau \int \frac{d^2p}{d\tau^2} dv . d\tau$$

and integrating

$$\left(k + \tau \int \frac{d^2p}{d\tau^2} dv\right)\tau = \text{constant},$$

or the temperature will remain constant.

d. Let there be no transmission of heat and external work be done. Then will $dH = o$, and we have

$$o = \left(k + \tau \int \frac{d^2p}{d\tau^2} dv\right) d\tau + \tau \frac{dp}{d\tau} dv$$

which is the differential equation of an adiabatic when τ and v are the variables, p being eliminated by means of the equation of the fluid (equation 1, page 319). The last equation cannot be integrated for the general case of imperfect gases. If expansion be adiabatic the pressure and temperature both vary, the three quantities v, p, τ, being so related that a definite change in one necessitates a definite change in both the others. Let the gas be perfect then

$$p=\mathrm{R}\frac{\tau}{v},\quad \frac{dp}{d\tau}=\frac{\mathrm{R}}{v},\quad \frac{d^2p}{d\tau^2}=o,$$

and the preceding equation becomes

$$k\frac{d\tau}{\tau}+\mathrm{R}\frac{dv}{v}=o \qquad (z)$$

Let the initial temperature in the state B be τ_2. corresponding to the volume $Ov_2=v_2$, and the corresponding values in the state b be τ and v_1, Fig. 21, and integrating between these limits we have

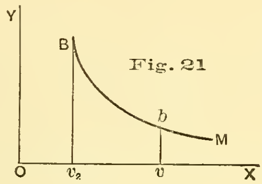


Fig. 21

$$k \log. \frac{\tau_2}{\tau}+\mathrm{R}\log. \frac{v_2}{v}=o$$

$$\therefore\ k\log. \frac{\tau_2}{\tau}=\mathrm{R}\log. \frac{v}{v_2}$$

$$\therefore\qquad \frac{\tau_2}{\tau}=\left(\frac{v}{v_2}\right)^{\frac{\mathrm{R}}{k}}=\left(\frac{v}{v_2}\right)^{\gamma-1} \qquad (az)$$

Eliminating τ and τ_2 by means of the equations

$$pv=\mathrm{R}\tau$$

$$p_2v_2=\mathrm{R}\tau_2$$

gives

$$\frac{v}{v_2}=\left(\frac{p_2}{p}\right)^{\frac{1}{\gamma}} \qquad (bz)$$

which is the equation of the adiabatic, equations (4) page 319 of the text. We may now find an expression for the area v_2Bbv, Fig. 21, which represents the work done during an adiabatic expansion for a perfect gas. Equation (z) becomes

$$k\int_{\tau}^{\tau_2}d\tau=\int_{v_2}^{v}\tau\frac{dp}{d\tau}dv=\int_{v_2}^{v}pdv \qquad (cz)$$

and substituting the value of p from (bz),

$$k\,(\tau_2-\tau)=\frac{p_2v_2^{\gamma}}{1-\gamma}(v^{1-\gamma}-v_2^{1-\gamma})$$

$$=\frac{p_2v_2^{\gamma}}{\gamma-1}(v_2^{1-\gamma}-v^{1-\gamma})$$

the second member of which is the area v_2Bbv, and the left member is heat lost; hence the loss of heat equals the work done, as it should as before shown. If now the expansion be extended indefinitely, v becomes infinite, and according to equation (az) τ becomes zero, and the preceding equation becomes

$$k\tau_2=\frac{p_2v_2}{\gamma-1} \qquad (dz)$$

The first member is, according to equation (y), the amount of heat imparted to a perfect gas forms an external source in

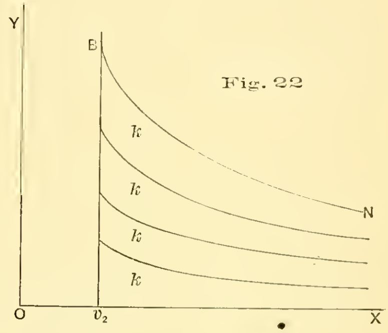


Fig. 22

raising its temperature from zero to the absolute temperature τ_2, and this equals, according to equation (dz), the indefinitely extended area $\mathrm{MB}v_2\mathrm{X}$. Let the ordinate v_2B (Fig. 22) be divided into as many equal parts as there are units in the absolute temperature, that is into τ_2 parts, and through each point of division an adiabatic be drawn and extended to the right indefinitely, then will the areas between any two consecutive adiabatics be equal, and if each be represented by k, the sum of all of them will be $k\tau_2$. Specific heat may be represented by a unit of the area representing heat.

For perfect gases we have

$$\frac{p_2v_2}{\tau_2}=\frac{p_0v_0}{\tau_0}$$

from which finding p_2v_2, and substituting in equation (dz), gives:

$$k\tau_2=\frac{p_0v_0}{\gamma-1}\cdot\frac{\tau_2}{\tau_0}$$

$$\therefore\ k=\frac{p_0v_0}{(\gamma-1)\tau_0}$$

which value is given on page 319 of text.

e. Specific heat of an imperfect gas.—As shown by equation (x) the expression for the specific heat in this case contains the term $\tau\int\frac{d^2p}{d\tau^2}dv$, which represents the amount of heat absorbed and stored in the body in doing internal work at the temperature τ for a change of temperature of one degree on the supposition that the *rate* of doing the internal work is uniform throughout the degree. It does not involve a change of volume—the heat thus absorbed does not affect the temperature—but disappears, as in all other cases where heat produces work. To find its value for a particular case, we again take the equation for carbonic acid gas. We have found, Equation (w)

$$\tau\frac{dp}{d\tau}=p+\frac{2a}{v^2\tau}$$

$$\therefore \frac{d^2p}{d\tau^2}=-\frac{2a}{\tau^3v^2} \qquad (ez)$$

and $$\tau\int\frac{d^2p}{d\tau^2}dv=-2a\tau\int_{\infty}^{v}\frac{dv}{\tau^3v^2} \qquad (fz)$$

The differentiations are performed on the supposition that τ is variable and v constant, but now the integration is to be made with τ constant and v variable. But whence this infinite limit, since the term has been produced from one containing the finite limits of expansion, as shown by equation (C).

The answer will be more clearly shown in the consideration of the more general case hereafter considered, but the fact may here be stated that since heat has been represented by an area, so here the value of the expression in equation (fz) is assumed to be an area representing an indefinite expansion at constant temperature. According to this view v now becomes an abscissa to such an *ideal* area, and not that of an *actual* expansion as appears in the expression pdv, and the use of the infinite limit at once becomes apparent. The author is not satisfactory on this point. He refers to it twice, once in our text and once in one of his original papers, and in neither case is a satisfactory explanation given, unless the one in the text be so considered.

There is probably no difficulty involved in the fact that v is constant during the differentiation. It is the case of a gas confined in an inextensible vessel—like a cylinder containing an immovable piston—the gas being heated from zero temperature or from any finite limit τ_2 to a higher temperature τ, but is impossible to find the total heat absorbed, or the internal work done from zero to τ, or even through a finite range of temperatures, as shown by Equation (fz), since τ is not a function of v only. In establishing the differential equation, however, we need only the work for an infinitesimal change of temperature, so that we may consider τ constant in (fz) in determining the coefficient of $d\tau$ of Equation (B), and the expression becomes

$$-\frac{2a}{\tau_2}\int_{\infty}^{v}\frac{dv}{v^2}=\frac{2a}{\tau^2v} \qquad (gz)$$

Whenever p in equation (v) is less than $R\frac{\tau}{v}$, the sign before equation (gz) will be negative, and since in this case the value of the second member must be *added* to k in equation (B), the infinite limit will be inferior.

In order to find a numerical value for this term it is necessary to assume definite values for τ and v. Taking $p=p_0=2116.4$ pounds, the pressure of the atmosphere on a square foot, $\tau_0=493.2°$ F., the absolute temperature of melting ice, $v_0=8.15725$ cubic feet in one pound of carbonic acid gas at the above pressure and temperature (page 229 of the text), and $a=3.42\times17264\times8.15725$, we have:

$$\frac{2a}{\tau_0^2v_0}=8.84\frac{17263}{(493.2)^2}=0.484 \text{ foot pounds.}$$

At 60° F.=512.2° F. absolute, the volume being the same, we have:

$$\frac{2a}{\tau^2v_0}=6.84\frac{17263}{(521.2)^2}=0.435 \text{ foot pounds.}$$

The real dynamic specific heat of this gas being 132 foot pounds, equation (B) becomes

$$dH=(132+0.435)d\tau+\tau\frac{dp}{d\tau}dv.$$

The second term in the parenthesis is so small compared with the other that it may be omitted for ordinary ranges of temperature. It is less than the limits of the errors of observation. Rankine treats it as constant, and then rejects it on account of its relatively small value (see remark on page 317 of the text).

This mode of treatment, however, is not theoretically correct, and very small values of τ and v give abnormally large results. Fortunately, we have no occasion to use values of τ so small as 1°, 10°, 100°, or even 300°, nor of v less than 3 or 4 cubic feet, and even with these extreme values the result will still be so small that it may safely be rejected. This part of the analysis is very refined, and we seriously question whether it accurately represents nature, and it is a consolation to know that it may be discarded in practice. The most important term, in dealing with imperfect fluids, is the third one in equation (B) and involved in the part $\tau \frac{dp}{d\tau}$.

The result as to pressure, volume and temperature may be conceived to be produced by compressing the gas from an indefinitely large volume along the adiabatic MA, Fig. 23, doing external work MAv_1X upon the substance, the internal work due to compression $MAam$, which will be negative, and conceived to be due to the attractions of the particles for each other, and therefore assisting in producing compression, and the internal work maa_1m_1 due to an increase of the temperature. Or, if the substance be expanded indefinitely from the state A, it will do the same amount of positive external work, and the internal work previously done by increasing the temperature will now be transmuted again into heat, which ultimately is conceived to become zero, being expended in doing work by an indefinite expansion. Since the adiabatic AM is determined by the relation between the volumes and pressures only, the work done by adiabatic expansion will be a function of the pressure and volumes only, or of the temperature and volume only. The *internal* work done by an adiabatic expansion is partly at the expense of actual heat, represented by the area $MAam$, and partly by the heat which became latent or potential on account of the increase of temperature, and represented by maa_1m_1.

Let $$\tau \int_{\infty}^{v} \frac{d^2p}{d\tau^2}\, dv = \text{P} \qquad (hz)$$

then will the integral of equation (B) be

$$\text{H} = (k+\text{P})\,(\tau_2 - \tau_1) + \int_{v_2}^{v_1} \tau \frac{dp}{d\tau}\, dv \qquad \text{(E)}$$

the last term of which cannot generally be integrated since the pressure p may not only be arbitrary, but $\tau \frac{dp}{d\tau}$ not a function of v only.

Let Ov_1, Fig. 23, be the volume of a pound of the fluid without heat or press-

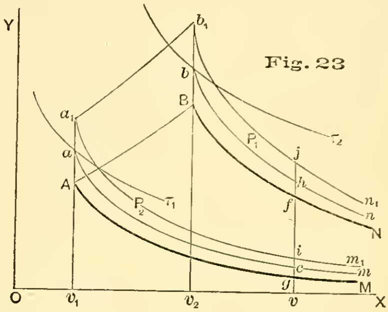


Fig. 23

ure, to which heat being communicated, the pressure will be raised to v_1A, while the isothermal representing the temperature passes through a, AM an adiabatic, am an adiabatic through a as for a perfect gas, and a_1m_1 a line following the general course of am, and becoming an asymptote to it.

From the state A let the substance expand from v_1 to v_2 and receive heat from an external source raising its temperature from τ_1 at A to τ_2 at B, doing the external, or visible work, v_1v_2BA, and the internal work due to expansion ABb_1a_1; and from the state B expand adiabatically doing the ideal external work NBv_2X and the internal work NBb_1n_1. The area nbb_1n_1 represents the latent heat due to raising the temperature from zero to τ_2. The several terms of equation (E) will be

$$k\tau_2 = nbv_2X$$
$$\text{P}\tau_2 = nbb_1n_1$$
$$k\tau_1 = mav_1X$$
$$\text{P}\tau_1 = maa_1m_1$$
$$\int \tau \frac{dp}{d\tau} dv = v_1v_2b_1a_1.$$

Hence Equation (E) is represented by the entire area of the figure $n_1b_1a_1v_1X$ less the area $m_1a_1v_1X$, or

$\text{H} = n_1b_1a_1m_1$ indefinitely extended. (E_1)

But if the fluid be worked in the cycle v_1 to A, to B, to v_2, to v_1; or better, in the cycle MABN, the internal work will be zero, or

$$AB b_1 a_1 + NB b_1 n_1 - MA a_1 m_1 = o \quad (iz)$$

which, subtracted from the second member of the preceding equation, gives

$$H = MABN \quad (E_2)$$

for the resultant integral of equation (E), as stated by our author on page 313. But to produce this result by algebraic analysis requires a further transformation.

Adding $\int pdv$ to equation (E), and subtracting it from the same, gives

$$H = k(\tau_2 - \tau_1) + \int_\infty^v \tau \frac{d^2p}{d\tau^2} dv (\tau_2 - \tau_1) +$$

$$\int_{v_1}^{v_2} \left(\tau \frac{dp}{d\tau} - p\right) dv + \int_{v_1}^{v_2} pdv \quad (E_3)$$

in which p is an ordinate to AB, and hence the last term expresses the external work performed during the expansion from v_1 to v_2 and equals $v_1 v_2$BA. The entire internal work performed by a rise in the temperature and an increase in the volume is expressed by the second and third terms, respectively. Let $p_2 = vf$ be an ordinate to the adiabatic BN and $p_1 = vg$ to AM, then we have for the strip above BN

$$\int_{v_2}^{\infty} \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv = NB b_1 n_1$$

and for that above AM

$$\int_{v_1}^{\infty} \left(\tau \frac{dp_1}{d\tau} - p_1\right) dv = MA a_1 m_1$$

and $$\int_{v_1}^{v_2} \left(\tau \frac{dp}{d\tau} - p\right) dv = AB b_1 a_1$$

and equation (iz) gives

$$\int_{v_1}^{v_2} \left(\tau \frac{dp}{d\tau} - p\right) dv = \int_\infty^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_3\right) dv$$

$$- \int_\infty^{v_1} \left(\tau \frac{dp_1}{d\tau} - p_1\right) dv \quad (jz)$$

The complete differential of the first term of the second member is

$$d . \int_\infty^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right) dv = \left(\tau \frac{dp_2}{d\tau} - p_3\right) dv$$

$$+ \int_\infty^{v_2} \tau \frac{d^2 p_2}{d\tau^2} dv \,.\, d\tau,$$

the last term of which now follows naturally from the analysis, the nature of which has already been explained. We have represented it by the area nbb_1n_1. The integral of the first member, considering both τ and v as independent variables, is also the integral of the second member, or

$$\int_\infty^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right)_{\tau, v} dv = \int_\infty^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right)_v dv$$

$$\int_0^{\tau_2} \int_\infty^{v_2} \tau \frac{d^2 p}{d\tau^2} dv \, d\tau,$$

$$= -NB b_1 n_1 + nbb_1 n_1 = -NB bn, \quad (kz)$$

and this is a function of the *temperature* and *volume* only, and hence implicitly of the *pressure* and *volume* only. The last term of equation (jz) may be expressed in the same form.

In regard to the signs of the terms of Equation (kz) we observe that we consider

$$\int_{v_2}^{\infty} \left(\tau \frac{dp}{d\tau} - p\right) dv$$

as positive, and by inverting the order of the limits it becomes negative, and we have written it $-NB b_1 n_1$; and in regard to the other term we have previously shown why it should be positive as it stands. Or, regardless of the resulting signs of the values following any order of integration, it will be observed that the result sought is the difference of the areas $NB b_1 n_1$ and $nbb_1 n_1$, and that this result is, ultimately, to be subtracted from nbv_2X.

Let

$$\int_\infty^{v_2} \left(\tau \frac{dp_2}{d\tau} - p_2\right)_{\tau_1 v} dv = -S_2 \quad (lz)$$

then

$$-S_2 = -NB b_1 n_1 + nbb_1 n_1 \quad (mz)$$

and similarly,

$$-S_1 = -MA a\, m_1 + maa_1 m_1 \quad (nz)$$

and these several equations finally reduce (E_3) to

$$H = k\tau_2 - S_2 + \int_{v_1}^{v_2} pdv - (k\tau_1 - S_1)$$

$$= MABN \quad (E_4)$$

A discussion of this equation should give essentially the same results as before found.

a. Let no heat be supplied. Then

$H=0$, and work will be done by an adiabatic expansion, and in Fig. 24 we have:

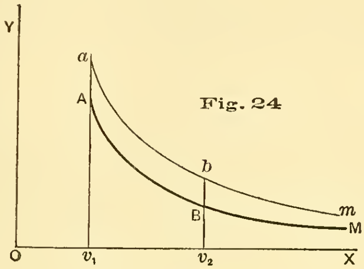


Fig. 24

$$k\tau_1 = mav_1X,$$
$$S_1 = MAam,$$
$$\int pdv = v_2v_1AB,$$
$$k\tau_2 = mbv_2X;$$
$$S_1 = MBbm,$$

hence, (Equation E_4),

$$\int_{v_2}^{v_1} pdv = -\int_{v_1}^{v_2} pdv$$
$$= (k\tau_2 - S_2) - (k\tau_1 - S_1),$$
$$= MBv_2X - MAv_1X,$$
$$= -v_2BAv_1.$$

b. Let no external work be done. Then $\int pdv = o$, and v_2 falls on v_1, and all the work will be internal during the increase of temperature. The equation becomes

$$H = k\tau_2 - S_2 - (k\tau_1 - S_1) \qquad (oz)$$

If $\tau_1 = o$, and $S_1 = o$, this becomes

$$H = k\tau_2 - S_2 \qquad (pz)$$

But to heat a perfect gas to the temperature τ_2 requires an amount of heat represented by $k\tau_2$, and it has been previously shown that to heat an imperfect gas to the same temperature requires a larger amount of heat, whereas, according equation (pz), it *appears* to require less in the latter case. But, according to equation (jz), the left member will be zero for this case, and the right member will give, Fig. 23,

$$NBb_1n_1 = MAa_1m_1,$$

(observing, however, that for this case v_1A will fall on v_2B), and this in equations (mz) and (nz) gives

$$-S_2 + S_1 = nbb_1n_1 - maa_1m_1,$$

if S_1 be zero, we have

$$-S_2 = mbb_1m_1,$$

and equation (pz) becomes

$$H = k\tau_2 + mbb_1m_1,$$

a result which agrees with previous analysis, and is consistent with the principles of the subject. This part of the discussion would be facilitated by substituting the values of S_1 and S_2 of equations (mz) and (nz), for S_2 become positive when no external work is done.

c. Let the temperature be constant. Then $\tau_1 = \tau_2$ and equation (E_4) becomes

$$H = \int_{v_2}^{v_2} pdv - S_2 + S_1.$$

In this case the last terms of equations (mz) and (nz) are equal, and we have

$$-S_3 + S_1 = -NBb_1n_1 + MAa_1n_1.$$

Professor Tait, an ardent admirer of our author says of him: "He was ambitious; that is obvious from the number and variety of his books and papers, and the quite unnecessary display of symbols in several of his less popular writings." But there was not an unnecessary display of symbols in explaining article 247 of the text. More explanations on his part would have been acceptable to the student.

In regard to article 248, in which p and τ are the independent variables, we regret that the author has not left a solution which is accessible, for we anticipate that it would contain some master strokes of analysis. A solution is given in McCulloch's "Mechanical Theory of Heat," in accordance with Rankine's suggestions but even when separated from other analysis in the work it is rather lengthy. Clausius carries the two cases together—first with v and τ as independent variables; and, secondly, with p and τ as independent variables—but the general solution is somewhat lengthy. We offer the following special solution:

Let W = the energy of the body, including the heat energy and the internal work.

$$U = \int pdv = \text{the external work.}$$

H = the heat imparted to the substance; then

$$dH=\tau d\varphi=dW+pdv \qquad (1)$$

$$\therefore \tau\frac{d\varphi}{dp}=\frac{dW}{dp}+p\frac{dv}{dp} \qquad (2)$$

$$\tau\frac{d\varphi}{d\tau}=\frac{dW}{d\tau}+p\frac{dv}{d\tau} \qquad (3)$$

in which p and τ are the independent variables. Eliminate W from these equations; to do which differentiate (2) in reference to τ, and (3) in reference to p, and subtract, giving

$$\frac{d\tau}{d\tau}\cdot\frac{d\varphi}{dp}+\tau\frac{d^2\varphi}{dp\,d\tau}=\frac{d^2W}{dp\,d\tau}+\frac{dp}{d\tau}\cdot\frac{dv}{dp}+p\frac{d^2v}{dp\,d\tau}$$

$$\frac{d\tau}{dp}\cdot\frac{d\varphi}{d\tau}+\tau\frac{d^2\varphi}{dp\,d\tau}=\frac{d^2W}{dp\,d\tau}+\frac{dp}{dp}\cdot\frac{dv}{d\tau}+p\frac{d^2v}{dp\,d\tau}$$

$$\therefore \quad \frac{d\varphi}{dp}-\frac{d\tau}{dp}\cdot\frac{d\varphi}{d\tau}=\frac{dp}{d\tau}\cdot\frac{dv}{dp}-\frac{dv}{d\tau}.$$

Now $\frac{d\tau}{dp}$ is formed by an assumed increment in p while τ is constant, $\therefore \frac{d\tau}{dp}=o$, and in the second member $\frac{dp}{d\tau}$ is formed by an assumed increment in τ while p is constant, $\therefore \frac{dp}{d\tau}=o$; which is in agreement with Clausius process (see "Mechanical Theory of Heat," translated by Browne, page 115). We thus have the partial differential equation,

$$\left(\frac{d\varphi_2}{dp}\right)=-\frac{dv}{d\tau}$$

or

$$(d\varphi)_1=-\frac{dv}{d\tau}dp$$

The partial differential equation $\left(\frac{d\varphi}{d\tau}\right)$ directly dependent upon the temperature is, from Equation (1),

$$(d\varphi)_2=\frac{dH}{\tau};$$

$$\therefore \left(\frac{d\varphi_2}{d\tau}\right)=\frac{1}{\tau}\left(\frac{dH}{d\tau}\right)$$

or

$$(d\varphi)_2=\frac{1}{\tau}\left(\frac{dH}{d\tau}\right)d\tau,$$

and the total differential will be

$$d\varphi=\left(\frac{dH}{d\tau}\right)\frac{d\tau}{\tau}-\frac{dv}{d\tau}dp,$$

which for a homogeneous body becomes

$$d\varphi=k_p\frac{d\tau}{\tau}-\frac{dv}{d\tau}dp \qquad (F)$$

where k_p is the specific heat at constant pressure, and in the case of fluids is considered constant at all temperatures and pressures. The integral is

$$\varphi=k_p\log.\,\tau-\int\frac{dv}{d\tau}dp$$

Since k_p is constant for a particular substance, we may find the form of its developed expression by using a perfect gas, for which we have

$$\frac{dv}{d\tau}=\frac{v}{\tau},\quad p=\frac{p_0v_0}{\tau_0}\frac{\tau}{v}=R\frac{\tau}{v}$$

$$\therefore dp=R\frac{d\tau}{v}-R\frac{\tau dv}{v^2}$$

which, substituted in (F), gives

$$dH=\tau d\varphi=(k_p-R)d\tau+pdv$$

which has changed the equation from τ and p independent variables to τ and v. But for a perfect gas, Equation (B) becomes

$$dH=kd\tau+pdv;$$

$$\therefore k_p=k+\frac{p_0v_0}{\tau_0}$$

and this substituted in (F) gives

$$\varphi=\left(k+\frac{p_0v_0}{\tau_0}\right)\log.\,\tau-\int\frac{dv}{d\tau}dp \qquad (G)$$

which is equation (1), page 314 of the text. It may also be written

$$Jdq=\left(Jk'+\frac{p_0v_0}{\tau_0}\right)d\tau-\iota\left(d\tau\frac{d}{d\tau}+dp\frac{d}{dp}\right)\int\frac{dv}{d\tau}dp$$

as given by the author in the *Philosophical Magazine*, 1856, (2), page 103.

THE DISTRIBUTION OF ELECTRICAL ENERGY.

From "Iron.'

In his recent inaugural address, the President of the Society of Engineers, referring to the Gaulard-Gibbs system of electrical distribution, observed that the installation at the Grosvenor Gallery, and its application to a number of establishments in the neighborhood, constituted "the first practical and commercial example in England of *bona fide* house-to-house distribution of the electrical current from a central station." The importance of the subject, no less from a scientific than a commercial point of view, induces us to look somewhat further into the matter. This we are enabled to do by the light of an interesting ing brochure which has recently been issued by the National Company for the Distribution of Electricity by Secondary Generators, Limited, whose offices are at 18 Warwick street, Regent street, London. This pamphlet deals with the question of electric lighting from a general point of view, and describes the development and progress of the Gaulard-Gibbs system from its first appearance before the public to its present successful issue. Turning first to the advantages of electric lighting, it is to be observed that the great superiority of the electric light over gas as an illuminant, and the marked advantages secured by its use, both from a sanitary point of view and for the preservation of books, pictures, art decorations and metallic ornamentation generally, from the injury inflicted by gas, are so well established that it is needless to dwell upon them here. A striking example of the results of the two methods of lighting was afforded during the gas and electrical exhibition held at the Crystal Palace in 1882–83. In the south nave, which was devoted to the exhibition of gas-lighting apparatus, the trees and shrubs suffered most severely, being materially injured after the exhibition had been open for a few weeks only, whilst at its close nought remained but, for the most part, a display of shrivelled leaves and fast withering stems. On the other hand, in the north nave, where the electric light was displayed, the plants and shrubs remained green and healthy to the last; the flowers, too, showing forth at night in all their brilliancy of natural color. But, given all the manifest advantages pertaining to the use of the electric light, the problem arose how the benefits conferred by this principle of illumination were to be made to reach the general public. It is manifestly out of the question that the average householder can afford to have an engine and a dynamo machine fitted on his premises. And even where such can be afforded, the space necessary for their proper location would in most instances be wanting. And yet this is all that, as a rule, could hitherto be offered by most of the electric lighting companies. It stands to reason that, if the employment of gas had necessitated the manufacture of that illuminating agent on the premises of the consumers, its use would have been considerably restricted. It is true that there is the accumulator system, in which the batteries are charged at the works, delivered at the consumer's house, called for when the contents have been used, recharged, and returned to the consumer. But how many are there who adopt this system for ordinary, regular every-day use? Probably not one, the only patrons of this system, doubtless, being those who elect to have their salons lighted by it on special occasions. And, after all, it is only the exact method adopted in distributing coal gas to consumers in the earliest days of its public use.

A retrospective glance at the recent history of electric lighting shows that its practical introduction for general purposes in this country dates from the year 1877, when the Jablochkoff electric candle, as it was called, was first exhibited as fitted up in a warehouse and on board a ship in the West India Docks. The next step was the adoption, in 1878, of this system on the Thames Embankment, where it continued in use till 1884 From the long stretch of road illuminated by this means it was thought at one time that the system was destined to subserve the most important purpose to which electric lighting can be applied, namely, general house-to-house illumination, the current being distributed over a given district from a central generating station. To this purpose, however, it never was and never could be applied, and the fact, moreover, remains that, although many systems of electric lighting have since been introduced, some of which are still doing good public service, not one, with the exception of the Gaulard Gibbs system, has succeeded in establishing a claim to be considered a practical distributing system, although in several instances such a claim has been seriously advanced. The main reason for this is that in every system except the Gaulard-Gibbs a primary electrical current is employed—that is, a current taken direct from the dynamo, led along a conductor just as produced, and used without undergoing any intermediate modification or change. To conduct such a current to any useful distance, and to divide it into a large number of small parts, so to speak—so as to distribute it over a large area in the form of numerous lights of moderate power—would require conductors of enormous diameter. The dimensions would be such as to preclude their use, both on account of their weight and also their cost, as they would necessarily have to be made either of copper or of bronze. The limit at which incandescence lamps can be practically lighted by any direct system is reached at 500 yards from the producing dynamo. Another disturbing element which presents itself in all direct systems is that of danger to life when a high tension current is used, as is the case when it is desired to light arc lamps over a considerable distance on a circuit not metallically closed.

The essentials of success in any system having for its object the distribution of electricity on a practical scale are the opposite of what has been stated. In fact, it can only be accomplished by the distribution, not of the electrical current itself, but of electrical energy represented by the current. It should be understood that the energy of a current is a very different thing from the current itself, inasmuch as every given current has special properties which are capable of being modified to meet varied requirements, or, conversely stated, every special purpose—such as arc lighting, incandescent or glow lighting, electroplating, and the furnishing of motive power—has to be provided for by a special current-transforming apparatus. Now, properly treated, a given primary current can be made subservient to all these purposes by means of one and the same intermediate apparatus or converter. Then, again, when produced, the distribution of this transformed current must be effected without danger to those who are using it; otherwise no system of production, however successful scientifically, can hope for public patronage. In fact, its dangerous character would prohibit its adoption, and hence it must fail commercially.

So far as present experience shows, the only system by which the conversion of primary into secondary currents can be efficiently, economically, and safely accomplished, and those converted currents satisfactorily utilised, is that of Messrs. Gaulard & Gibbs. This system of secondary generators is founded upon the results of experiments made many years ago by Ampère, who demonstrated that bobbins of insulated copper wire were influenced by electric currents being passed through them. The phenomena of induction were also studied by Faraday, and his investigations threw still further light upon the results obtained by Ampere. Proceeding to give practical effect to the experiments of Ampère and Faraday, Messrs. Gaulard & Gibbs constructed an apparatus in which the main feature was an insulated copper wire conductor of comparatively small diameter, surrounded by other finer insulated wires. These wires were coiled spirally. The main wire was connected up with a dynamo machine capable of producing an alternating current, whilst the spiral covering wire was continued to the lamps. Upon the machine being started, a primary current was produced, which, traversing the main wire, induced another or secondary current in the spiral covering wire, which current could be rendered capable of application to either arc or incandescence lamps, or to the driving of machinery. The principle upon which the system depends is that the primary and secondary conductors shall be of equal mass and equidistant from the iron core. The secondary generator is composed of columns, and these columns are divided up into groups, and so connected as to admit of the current induced on the secondary conductors by the influence of the alternating current which traverses the primary conductor being made to develop at will different potentials—that is, the different qualities of current required respectively for arc lamps, incandescence lamps, and motive power. An important feature of the system is that a metallically closed circuit is used to convey the primary current. Hence no limit need be fixed to the electro-motive force of the current, which, on such a circuit, may be rendered absolutely free from danger.

Such is the principle of the Gaulard-Gibbs secondary generator, the first public exhibition of which took place in the Electric Lighting Exhibition, which was held in the Royal Aquarium, Westminster, in 1883. This machine consisted of sixteen parallel columns, placed vertically between a base and an entablature of wood, to which they were individually attached. Each column was formed of a hollow cardboard cylinder two inches in diameter, around which was coiled, in two layers of superposed spirals, a cable composed of a central copper wire an eighth of an inch in diameter covered with a double layer of paraffined cotton. Around this central wire, which formed the main conductor of the primary current, and completely enveloping it, were placed in parallel order six cables, each composed of eight fine copper wires similarly insulated by a double layer of paraffined cotton. By this arrangement the inductive reaction which would occur in the spirals of the primary circuit if they were placed next to each other was prevented. The columns were disposed in four groups of four each, and were so arranged that the terminals of their inductor were brought to the commutator placed in front of the apparatus, the object of which was to direct the primary current by one or more of these groups of columns. The terminals of the secondary wires were themselves conducted to four circular commutators of identical construction placed on the side of the apparatus, the object of which was to couple these terminals by means of a simple handle, either in parallel order or end to end. By means of these commutators the individual ends of each column could be connected separately or in groups to the apparatus of consumption, whether lamps or motors, which the secondary generators had to supply with a current. In the centre of each column was an iron wire core, the magnetic action of which was regulated by means of a movable brass cap or cylinder. These cylinders emerge from the upper portion of the generator, their function being to graduate the intensity of the secondary current, and therefore the intensity of the light produced at the lamps, and this it did most effectively. The brass cylinders were moved up and down, or, in other words, the intensity of the current was regulated by means of four hand-wheels just under the entablature. A striking characteristic of this apparatus was that, although traversed by currents of the highest potential, every exposed metallic part might be touched without the risk of receiving a dangerous or even an inconvenient shock.

The first practical application of the Gaulard-Gibbs system, as already stated, was made on the Metropolitan Railway in December 1883. The generating machinery, which was located at the Edgeware Road Station, consisted of a 25 horse-power steam engine, which ran at a speed of 120 revolutions per minute, and was supplied with steam from a Cornish boiler at 60 lb. pressure per square inch. The engine drove, through a countershaft, a Siemens W° alternating current machine, running at 600 revolutions per minute, and excited by a small Siemens dynamo running at 1,000 revolutions per minute, the large dynamo giving 16,000 alternations per minute. The primary wire was led from the large dynamo to the secondary generator, which supplied the current to a series of arc and incandescence lamps in the booking-office and on the platform of the station. After traversing the generator, the primary wire was carried out of the station and along the course of the line at the side of the tunnel to Notting Hill Gate station. It returned thence to Gower street, King's Cross and Aldgate, and back again to the Edgeware Road, being intercepted by secondary generators, and the current tapped and used for lighting at five different stations altogether, including that at the Edgeware Road. The primary circuit in which these generators were placed was composed of a single wire fifteen miles in length and only one-eighth of an inch in diameter. This primary circuit was metallically closed throughout its entire length with the terminals of the dynamo machine at the Edgeware Road station. The management of the secondary generators was found to be so simple that from the first, and during the whole of the five months the system was in use on the line, the apparatus was left in the care of the inexperienced employes of the railway company. The results proved highly satisfactory, and as regards the effective work, it was shown by Dr. Hopkinson to be 90 per cent. In fact, it was practically demonstrated that the loss occasioned by the transformation of electrical energy into light did not exceed 10 per cent.

The experience gained during the practical trial of the system on the Metropolitan Railway led to several modifications being made in the form of the apparatus, although the principle remained precisely the same as in the first instrument shown at the Westminster Aquarium exhibition. The improved form of apparatus embodies the most simple and practical method of applying economically the principle involved. Further research has led to the formation of the inducing and induced circuits by means of copper discs, superposed and furnished with ear-pieces, by which they are connected together.

Considerable as was the circuit of 15 miles on the Metropolitan Railway, it was greatly exceeded in the second installation, which was carried out at the Turin Exhibition in 1884. Here electrical energy was transmitted to a distance of 25 miles from the machine along a single conductor, which formed, consequently, a circuit of twice that length, or 50 miles. Electric currents of varying potential were developed at the extremity as well as at several points on the circuit, forming an unprecedented fact in the history of electric lighting. A Siemens dynamo of 60 horse-power, supplying a current of 3,000 volts and 10 amperes, was placed in the exhibition, and the conductor, a bronze uninsulated wire one-eighth of an inch in diameter, was carried by insulators on the ordinary railway telegraph posts to Lanzo, a town at the foot of the Alps, and twenty-five miles distant by the line of telegraph posts from the exhibition. In the exhibition building several secondary generators were used for supplying electrical currents to various kinds of lamps, whilst other generators were placed at different points on the circuit for the same purpose. Thus the railway station at Turin and those at Venaria Reale and Cirié *en route* were brilliantly illuminated by means of both arc and glow lamps. The Lanzo station was similarly illuminated by arc lamps of the Siemens and the Sun types, and by glow lamps of the Swan and Bernstein patterns, tastefully distributed over the interior and exterior of the station, and fed through several columns of Gaulard-Gibbs secondary generators by currents generated 25 miles off at Turin. This installation formed the subject of long and exhaustive investigation by the international jury of the electrical section of the Turin exhibition, and thoroughly demonstrated the value of the system. The practical outcome was that, by the verdict of the jury, a prize of 10,000 fr. (out of 15,000 fr. placed at their disposal for prizes in the electrical department) and a gold medal were awarded in respect of the invention.

The most recent installation is that at the Grosvenor Gallery, which has been undertaken by Sir Coutts Lindsay & Co., Limited, and where for several months past the secondary generator system has been in operation on a gradually extending scale, having been successively applied to a number of establishments in Bond street and the neighborhood. Messrs. MacKenzie & Brougham, of 15 Great George street, Westminster, are the engineers to this installation. At the International Inventions Exhibition held in Landon in 1885, the National Company for the Distribution of Electricity by Secondary Generators, Limited, distributed by means of a Siemens dynamo current to various types of electric lamps. They were awarded by the jury a gold medal for "the successful working out of a system of electrical distribution by induced currents." At Aschersleben, in Germany, an installation has recently been completed, and is working most satisfactorily, comprising the distribution of 200 horse-power in light over a circuit of about six miles; some of the lamps being employed to light a mine. In this case the first practical application of the system will be made to the distribution of mechanical power. The current supplied by the secondary generators is also to be used for electro-chemical purposes. The lighting of the town of Tours, in France, is about to be inaugurated, the installation of the first 200 horse-power plant and machinery having been completed. In Italy installations will shortly be completed for supplying lights to the towns of Turin and Tivoli by the company's system, and arrangements are in progress for transporting 2,000 horse-power, derived from the waterfalls of Tivoli, from Tivoli to Rome, to be applied in lighting the principal part of the latter city. In the United States of America an eminent firm—Messrs. Westinghouse, of Pittsburgh—has undertaken to work the system. We have now indicated the development of this promising system, and, after an impartial consideration of the facts stated, we cannot evade the conclusion that it has made material progress—a progress which, as far as we are aware, is without a parallel in this country as regards house-to-house distribution of the electrical current.

EXPERIMENTS WITH LIGHTHOUSE ILLUMINANTS.

By E. PRICE EDWARDS.

From the "Journal of the Society of Arts."

Before entering upon a description of the experiments with lighthouse illuminants which were carried out at the South Foreland in 1884-5, I think it proper to state that it would be out of place, on the present occasion, to refer to any personal considerations which may have been connected with the question of setting these trials on foot, therefore I shall address myself solely to the practical view of the subject, and endeavor to present to you, from my own knowledge, a dispassionate and impartial account of these important experiments, and put before you the conclusions which may be legitimately drawn from them.

For the benefit of those not technically acquainted with the details of lighthouse illumination, I must make some preliminary observations of a general character.

For very many years the illumination of lighthouses has been an attractive subject for the efforts of earnest inventors, and the suggestions of fanciful speculators. I will not detain you with a recital of the numerous schemes which, from time to time, have been put forward, but will at once tell you that the only illumating agents which have successfully borne the tests of experiment and experience, and have been found to be serviceable for lighthouse purposes, are oil, gas, and electricity. The cardinal principle in connection with the maintenance of our coast lights is certainty; there must be no breakdown of the lights between sunset and sunrise. Mariners approaching our shores at night from distant parts are almost entirely dependent upon their sure and effective exhibition. Each one must be readily and certainly recognizable, in accordance with the advertised intimations of its special characteristic. In fulfillment of this essential condition it has come to pass, by a process analogous to that of the survival of the fittest, that oil, gas, and electricity remain the only sources of light upon which complete dependence may be placed for the purposes of effective lighthouse illumination.

In continuation of these preliminary remarks it will be useful to consider the general subject under three headings:

1. The actual sources of light.
2. The mechanical means by which the light is sustained and controlled.
3. The appliances for utilizing the light produced in the manner most serviceable to the mariner.

As each of the above named divisions would, in itself, afford ample material for a paper, I must ask you to forgive my touching them with a light hand only. My object will be simply to give those of my hearers to whom the subject is unfamiliar some general notions which will make the latter portions of my remarks more intelligible to them, and to connect the general principles of lighthouse science with the investigation at South Foreland.

1.—SOURCES OF LIGHT.

Oil.—Regarding these three illuminants as mere sources of light without reference to burners, lenses, or any of the appliances used in ordinary lighthouses, we will first give our attention to oil, which is the oldest of the three, its use dating back for nearly 100 years, when it began to replace the coal fire and candle systems of the last century. For the greater part of this long period sperm oil was used, but in 1845 it was demonstrated that rape seed or colza oil could be burned as effectually and at much less cost, and the use of sperm was discontinued. In modern times mineral oil has come to the front, and threatens to supplant the vegetable oil entirely, being very much cheaper, and giving an illuminating effect almost, if not quite equal to that of rape oil. The latter is, however, still employed at isolated rock lighthouses and on board lightships, chiefly for considerations of safety. The mineral oil now used in this country is paraffin obtained by the distillation of shale, and is at present supplied with a flashing point of 154° Fahr., thus rendering it a perfectly safe oil for use in this climate. Quite recently, a mineral oil, having a flashing point above 250° Fahr., has been tested with most encouraging results, which, if corroborated by further tests, will make it very suitable for rock lighthouses and lightships, and will tend to shut out rape oil altogether, the latter being fully twice the price of the new product. It is a coincidence that vegetable should displace animal oil, and that mineral should now be about to supplant vegetable oil. With some few exceptions, which will be referred to in dealing with gas and electricity, oil is the general illuminant now used in lighthouses of the United Kingdom, as well as in all parts of the world. In this country rigorous tests are applied to ensure the oil sent to lighthouses being of the very finest quality. Both rape and paraffin must burn without requiring to be trimmed for 16 hours. Careful examination of each is made to ascertain if any acid is left in, or other deleterious compound mixed with either kind of oil. The requirements in respect of the paraffin now used are that it must have a specific gravity between .810 and .820 at 60° Fahr., with a minimum flashing point of 140° Fahr. (close test), and must distil between the temperatures of 302° and 572° Fahr. The conjunction of such qualities as are indicated by the above requirements provides an effective and, in other respects, suitable oil for burning in lighthouses.

So far as the experiments at the South Foreland are concerned, rape oil need not be taken into consideration. Paraffin of the description above referred to only was used, and may be regarded as the representative of the oil system.

An important point may perhaps be here appropriately referred to in connection with the cost of lighthouse oil. In the early stages of the discussion as to the relative advantages of gas and oil, about twelve or fifteen years ago, economical arguments in favor of gas were based on the then prices of rape oil, which were variously quoted as 4s. 9½d., 3s. 10½d., 2s. 9d. per gallon. In these days paraffin is supplied at 6d. per gallon, a fact which obviously changes the financial aspect of the comparison very considerably.

Gas.—In the year 1865, Messrs. Edmundson & Co., of Dublin, of which firm Mr. J. R. Wigham is an enlightened and enterprising member, perfected a system by which gas could be employed as a lighthouse illuminant. At first gas made from oil was employed; but subsequently cannel coal gas was adopted. This illuminant was first established at the Howth Bailey Lighthouse, shortly afterwards taken to that at Wicklow Head, and subsequently extended to seven other lighthouse stations in Ireland, and one in England.

The gas used is obtained, by the usual process of manufacture, from the best cannel coal, and gives an illuminating power much higher than that of gas made from ordinary north country coal, such as is used in gas works of towns where a large supply is required to be distributed. Burned in the London standard Argand burner, the gas from north country coal does not give a light superior to that of sixteen candles, as required by Act of Parliament; whereas the gas made from good cannel coal, when burned in the London standard burner, yields a light almost equivalent to that of about thirty candles. For lighthouse purposes it is essential to have the best light, and therefore cannel gas has been exclusively employed, although much dearer than north country coal. The average price of cannel delivered at the lighthouses appears to range between 40s. and 50s. per ton. A quantity of furnace coal, about one-half that of the cannel coal carbonized in the retorts, is required for each gas works, and the whole manufacture has to be carried on at the lighthouse station. The cannel coal used at the South Foreland was chosen by Mr. Wigham as best adapted for the experimental gas light to be exhibited, and came from the Lesmahagow pit.

In addition to the use of cannel gas, trials were also made at South Foreland with gas obtained from mineral oil, which proved to possess an illuminating power equal to that of 46 to 50 candles. The gas-making apparatus was put up at South Foreland by Pintsch's Patent Lighting Company, as exemplifying their system of making gas, which is of a simpler character than that of cannel gas. The works are smaller, and consequently cheaper, and the operation of gas-making can be carried out by one man alone. The oil used is paraffin, not refined, and is supplied at South Foreland at about 6d. per gallon, but would be cheaper delivered in London. The oil is caused to drip on to a tray placed in the retort, where it is heated sufficiently to convert it into gas, which, after passing through some purifying operations, goes into the gas-holder. As compared with cannel gas, the higher illuminating power of Pintsch's oil gas, in conjunction with the comparative simplicity of manufacture and economy of gas-making plant, all point to its probable superiority for lighthouse purposes. The data at my disposal are not sufficient to enable me to say with certainty whether the cost per 1,000 cubic feet is less than that of an equal quantity of cannel gas, but even assuming the price to be the same in both cases, the higher illuminating power of Pintsch's gas would make it at least 25 per cent. more valuable as an illuminating agent.

During the trials at South Foreland the bulk of the comparisons were made with cannel gas, and a small proportion only with Pintsch's oil gas.

Electricity.—The next division of our sources of light has reference to electricity. This illuminant has been employed with success in certain lighthouses in this country since 1862. In France it was first used in 1863, but of late years it has received a very considerable impetus in that country. The limited application of this luminary in the United Kingdom is not due to any practical difficulties in respect of its installation, but rather to a dislike on the part of mariners of its extremely dazzling and distressing light when they are close to it. The navigable channels leading to and from our ports and harbors are mostly near land, and are often crowded with shipping; a very dazzling light shining across the navigation at such a place would be likely to prove a source of danger rather than of safety. Chiefly on this account electricity has made but slow progress as a lighthouse illuminant in this country.

In 1857 the discovery by Faraday, of magnetic induction in a coil of copper wire, was turned to practical account for lighthouse illumination by Professor F. H. Holmes, who then made the first complete magneto-electric machine. In that year trials with the newly-born electric light were commenced at South Foreland, and were continued until 1859. Then it was discontinued at South Foreland, but established at Dungeness lighthouse in 1862. After some further experience a new lighthouse on Souter Point Coast of Durham was lighted up with the electric spark, and in 1872 it was brought back as a permanency to its first home at South Foreland, and has shone there successfully ever since. In 1874 it was removed from Dungeness, because the point was low and dangerous, and mariners did not like the light in their eyes, and could not judge their distance from the point. In 1877 it was taken to the Lizard lighthouse. It is now intended to show electric light from the lighthouse on St. Catherine's Point, Isle of Wight, and from the high tower on the Isle of May, Frith of Forth.

The machines originally employed for generating the necessary electrical energy were constructed on the magneto-electric principle, which necessitates the use of permanent magnets for the induction of electricity. I have mentioned that Holmes made the first machine on this principle, and Holmes' machines are at present employed, after running fourteen years, in maintaining the lights shown from the permanent lighthouses at South Foreland. In 1876, some trials were made with various electric generators, to ascertain which kind of machine was most suitable for producing the electric light for lighthouses. The verdict was in favor of Siemens' dynamo machines, and accordingly these machines were adopted for the Lizard Station in 1877.

In consequence of some serious irregularities in the working of these machines, and because at the time Baron de Meritens, of Paris, had perfected a very powerful and in some respects novel form of magneto-electric machine, it was resolved to send one of these new generators to the Lizard, where it has worked most satisfactorily for several years. The experience gained at Lizard suggested that for the St. Catherine's station, which it had been resolved to illuminate with electricity, the De Meritens' machines should be employed, and they were accordingly ordered; but as arrangements were then being made for the South Foreland experiments, it was agreed that these machines should be sent direct to South Foreland, to be used in the trials, and to be operated by the steam-engines already established there, there being a reserve power beyond what was required for the permanent electric lights. The De Meritens machine consists of five star-like rings, fixed parallel to and a little distance from each other. Each ring carries twelve permanent magnets of horse-shoe pattern, with their poles converging towards a central horizontal shaft. Upon the shaft are mounted five brass wheels or discs, which revolve within and in front of the poles of the magnets. Each wheel carries twenty-four helices or coils on its periphery, and one revolution causes the twenty-four coils of each disc to pass the twenty-four poles of the twelve magnets in each ring, thus producing alternate currents o positive and negative electricity. The machine is worked at a speed of 600 revolutions per minute, and the result may be popularly stated thus:

Coils.		Poles.		Rings.		Revol.	
24	×	24	×	5	×	600	=1,728,000 pulsations

of alternate electricity generated in one minute. The electrical energy so excited is taken off by collectors at the ends of the shaft, and conducted by leads to the lighthouse lantern. At the South Foreland the distance between the generating machines in the engine room and the electric light lantern was 850 feet, and Professor W. Grylls Adams has shown that one-third of the united energy developed was expended in overcoming the resistance of this great length of conducting wire. Had the generating machines been close to the lantern, the electric light exhibited would have been reinforced by one-third more electrical energy than actually reached it. As a matter of fact, these machines were made for the St. Catherine's station, where they will be only a very short distance from the lighthouse.

During the trials the machines were worked either singly or coupled up with two machines in series, and occasionally with three machines in quantity. The lights shown were produced by either—

One machine with an average current of 125 ampères, and E.M.F. of 51 volts,

Two machines in quantity for one arc-light with an average current of 172 ampères, and E.M.F. of 60 volts.

Two machines in series for one arc-light, with an average current of 180 ampères, and E.M.F. of 60 volts.

Three machines in quantity for one arc light, with an average current of 180 amperes, and E.M.F. of 60 volts.

The three machines could not be coupled up in series, and the result of their being coupled in quantity is not so good as the two machines in series, which gave a current of 182 ampères. The high resistance with the three machines was due to the fact that the leads were not suitable for the current from three machines. It will be seen that the most effective results were obtained with two machines coupled in series feeding one arc-light.

II.—THE MECHANICAL MEANS BY WHICH THE ILLUMINANT, WHEN PRODUCED, IS SUSTAINED AND CONTROLLED.

In the case of oil this important function is performed by the burner. I shall not occupy your time by giving an historical account of the development of the oil-burner from ancient days, but a few observations on the general principles upon which oil-burners for lighthouses are constructed may perhaps be acceptable.

It is tolerably well known that when oil is consumed in a lamp it is converted into vapor by heat, and that the oil vapor so produced is, by the application of flame, caused to combine chemically with the oxygen in the surrounding atmosphere. In point of fact, an oil-burner is analogous to a miniature gas-works, where the gas is consumed as fast as it is manufactured. An ordinary mineral oil-burner is connected with a reservoir containing oil below it by means of a cotton wick, the lower end of which is in direct contact with the oil, the upper end just above the top of the burner. By capillary action the oil creeps upward until all the wick is saturated up to the point where the oil is to be converted into vapor, the application of flame only being required to complete vaporisation and set burning. The supply of oil must be properly regulated. With heavy fatty oils, such as rape or sperm, the capillary action is not vigorous enough to bring up from a receptacle below a sufficient quantity to keep the light going, and in that case the actual level of the oil immersing the wick must be closed to the burning point. With mineral oil the level may be two or three inches below the burning point, and its capillarity will be sufficiently active to conduct it to the top. In the case of large lighthouse lamps, the main reservoir is kept at a considerable distance below the burner, and mechanical means are employed to force the oil up to the required level, and to keep it constant for either a heavy or a light oil. To make combustion perfect, and to prevent smoke and soot, a plentiful and well-regulated supply of oxygen is essential. In the latter part of the last century, Argand demonstrated practically how such a supply could be secured for a single circular-wicked lamp, and the principle then laid down has ever since been followed in the development of the construction of lamps for burning oil. In this Argand burner you see a central tube, to which air has access at the bottom; the wick surrounds this tube, and in burning gives a circular flame, fed by the air coming up the centre. The glass chimney on the outside regulates the admission of air to the outside of the ring of flame, and thus perfect combustion is effected. A further development of the principle was made by Fresnel, who produced a burner consisting of four concentric wicks, with an air space separating each wick case, and the large glass chimney enclosing the flame completed the arrangement. Sir James Douglas increased the number of rings by two, producing the six-wick burner, which is now, and has for many years been used in many English lighthouses, and was the representative oil-burner employed in the South Foreland experiments. It should, however, be mentioned that Sir James Douglass had proceeded still further, and had produced seven, eight, and nine-wick burners, constructed on an improved principle, by which the flames are compressed at the focal plane, so that their diameter is not much greater than that of the six-wick burner, while the intensity of the light is considerably enhanced. These burners were not sufficiently perfected when the experiments began, and the bulk of the comparisons were therefore made with the six-wick burner. But they now are brought into good working order, and there is every reason to believe they will, before very long, be adopted for lighthouse work, and their increased efficiency will add much to the effectiveness of the lighthouses where they are employed.

In connection with this part of the subject it is necessary to bear in mind that oil-burners require careful looking after, that glass cylinders are a necessity, and that wicks of unusual size and very superior quality have to be provided.

For burning gas, the arrangements are certainly more simple. The gas is led by pipes to the burner in the ordinary way, a cock is turned on, and the gas lighted. It then burns without requiring serious attention as long as the gas supply lasts; it requires no glass cylinders nor wicks, no trimming, and little cleaning, all of which are points in favor of the gas system. The gas-burners used in lighthouses, and as exhibited at the South Foreland, are those of Mr. Wigham's patent. In its complete form the burner consists of five rings of gas jets, the innermost ring having 28, the next 48, the next 68, the next 88, and the outermost 108 jets, the diameter of each ring being respectively 4, $6\frac{1}{2}$, $8\frac{1}{2}$, $9\frac{1}{2}$, and $11\frac{1}{4}$ inches. With the gas burning, this congregation of jets packed in the space of a circle $11\frac{1}{4}$ inches in diameter gives a flame of considerable intensity, to which the air has perfectly free access, there being no glass chimney surrounding it, as in the case of an oil light. This huge flame is controlled in a great measure by the draught of the flue, the lower part of which is of talc, and, with the latest improvements, as developed during the trials at South Foreland, terminating in a sharp frustum of an inverted cone, and into the lower opening of which the tongues of flame rush in, leaving naked the thickest and most intense portion. This tends to preserve the flame in a uniform shape, which object is also materially assisted by a further improvement, introduced during the trials, of a talc collar fixed upon a collar of perforated zinc, encircling the lower part of the burner. Air passes through the perforations on to the outer surfaces of the flame, and, besides assisting to control the shape of the flame, renders combustion of the gas more vigorous. The reason for employing talc is because it is transparent, and allows a good deal of light to pass through, and strengthen the general illuminating effect, which would be lost if the cases and collars were made of an opaque material. From the blaze of 108 jets, the flame can readily be reduced to that of either 88, 68, 48, or 28 jets. The facility with which this can be accomplished is unquestionably one of the merits of this Wigham gas-burner, the mercury joint for each segment being a specially ingenuous arrangement.

Two well-known gas-burners were sent for trial at South Foreland, one the patent 6-ring burner of Mr. Sugg, the other a large size Siemens' regenerative burner. So far as the working of these burners under ordinary conditions is concerned, there is no fault to find with them, but as they proved to be unsuitable for lighthouse purposes, I need not dwell upon them.

Sir James Douglass' 6 and 10 ring gas burners, constructed on principles similar to those of his improved oil burners before described, gave results so satisfactory in the trials, that they must not be passed by. Instead of from jets, as used by Mr. Wigham, the gas issues from surface holes in concentric rings, and each ring forms a complete cylinder of flame, fed on both sides by the air ascending the spaces separating the rings. As in the oil burners, the rings of flame are compressed to the smallest diameter possible at the focal plane. No talc cone or collar is required for Sir James Douglass' burner, but a glass cylinder is necessary to preserve the shape of the flame, by regulating the air supply to the external surface of the outermost ring of the flame.

We now come to the arrangements for the electric light. Assuming the requisite current to be brought with uniform steadiness to the lighthouse lantern, by suitable conducting wires or leads, the regulation and control of the arc light produced between two carbon terminals are mainly dependent upon the action of the lamp or regulator, the delicate and ingenious mechanism of which keeps the carbon points as nearly as possible the same distance apart. The carbons originally used were supplied by Baron de Meritens, and were square in section, made up of a number of smaller square carbons, the entire bundle being 40 m.m. square. The heat caused the metallic bands by which the carbons were bound together to melt, and the consequence was that the small carbons frequently fell out while the light was being exhibited. Other carbons, circular in section, and solid throughout, 30 and 40 m.m. in diameter, were also tried; but those which gave the best results in the trials, and were used most frequently, were the Berlin core carbons, supplied by Messrs. Siemens, 40 m.m. in diameter, and with a core of graphite running through the centre. With alternating currents the electric arc can generally be maintained with a fair amount of steadiness with carbons that are tolerably homogeneous in their composition, but there is always a liability to momentary fluctuations, caused perhaps by the current seeking to make its exit by the direction of least resistance, and thus selecting the weakest parts of the carbon. The incandescence is thus liable to be transferred from side to side, and this gives rise to the appearance of momentary fluctuations. This, however has not been found to be a very serious drawback on the whole; indeed, in one sense, it may be advantageous, as conferring a marked individuality upon the electric light, enabling it to be more easily recognized. The Berlin carbons, with their graphite core, were found to burn with exceptional steadiness. possibly because the centre core affords the current an easier and consequently more regular course.

It may be mentioned that some 50 m.m. carbons were burnt in the engine-room close to the generators, with the full current of two machines in quantity without loss; the result being a current of 400 ampères with a low E. M. F. of 45 volts only.

Before proceeding to the consideration of the third division of the subject, it is desirable to make reference to what is known as the superposing system of lights. This was first introduced by Mr. Wigham, in connection with his gas system, by placing in a lighthouse lantern two, three or four burners vertically over each other, with a distance of three or four feet between them. By this means a column of light of great power is obtained, which it was supposed would rival the strongest electric light, and thoroughly eclipse oil. Without reference to any patent right in connection with this matter, which is not only beside the question of the relative merits of the illuminants, but has, I believe, been completely disposed of since the point was brought forward, the question naturally arose—can this method of piling up lights be applied equally well to electricity and oil? No doubt at all existed as to electricity, but as regards mineral oil, it was feared that its tendency to give off inflammable vapor at high temperatures would prevent the placing of such lights at short distances above one another, as the oil might become dangerously heated. Sir James Douglass, however, effectually disposed of any doubt on the subject by putting up three mineral oil burners one above the other, in the oil lantern, at South Foreland, each lamp being fed from one reservoir placed below the floor of the lantern, and the oil being, by suitable pressure and regulation, forced up the respective burners by pipes, and maintained at the necessary constant level. It is important to note that only three oil burners were superposed, while four gas burners were superposed in an equal vertical space. This will show that the oil burners were separated by greater distances than the gas lights were. The iron chimneys which carry off products of combustion and regulate draught in the case of the oil lights were cased with asbestos cloth and silicated cotton wool, to check radiation of heat from the iron surfaces; thus the heat was kept down very successfully in this lantern, and from the experience gained at South Foreland there is no doubt that four oil lights could have been as safely maintained as three. The electric lights were also arranged to be superposed, but with three lights only, as with the oil lanterns. The terms used for describing the different order of superposition, are biform, triform, and quadriform, representing the superposition of two, three and four lights respectively. It is not necessary to enter into further details concerning this method, but future references to biform, triform and quadriform will now be intelligible to those who have not been familiar with the subject.

III.—THE APPLIANCES FOR UTILISING THE ISSUING RAYS IN THE MANNER MOST SERVICEABLE TO THE MARINER.

I must again ask the indulgence of the audience in dealing with this part of my paper. Of necessity I must trouble you with some further elementary details, in order to make the whole matter clear.

With any of the illuminants of which I have spoken, burning under the most favorable conditions, and radiating light in all directions, it is clear that some provision must be made for using the issuing rays to the greatest advantage for the purpose required. The light is wanted by the sailor to shine upon the sea; but many rays, if they followed their ordinary course, would go up into the sky; many others would fall on the floor of the lantern. In the case of a lighthouse on shore, many rays would, under ordinary circumstances, go landward. In none of these directions is light wanted to be sent for the sailor's benefit. It has, therefore, been necessary to devise a method of utilizing such diverging rays. At first this was accomplished by metallic reflectors, and a considerable amount of success was and is still attained by this method. I need not enter into details respecting the principles of reflection; the subject is too well known. But in 1821, the celebrated Augustin Fresnel perfected an arrangement of glass lenses which, with a single large burner, accomplished the object in view much more effectively and conveniently than with a number of small burners with reflectors. Fresnel, in conjunction with Arago, had invented an oil burner with four concentric wicks, the diameter of the flame being 3⅝ inches. This, however, he placed in the center of a system of lenses and prisms built up at the proper focal distance around it, so that nearly all the light rays emitted were received upon some part or other of the inner surface of the lenticular structure, the lenses and prisms being so adjusted that, by the well understood action of refraction, the rays were caused to issue from the other side of the glass in a consolidated beam, illuminating only the sea area between the distant horizon and the near shore.

For a fixed light required to show continuously with equal effect over a given arc or circle, vertical condensation only is requisite, the rays being allowed to diverge horizontally without restriction. For this purpose a central refracting belt is employed, with rows of totally reflecting prisms above and below running parallel to it. The proper adjustment of this apparatus causes a beam to issue which illuminates the sea area within the horizon in a constant manner.

For a revolving or flashing light it is necessary to cut up this all round continuous beam into segments. As before, the rays must be condensed vertically, but in addition they must be condensed horizontally in bundles, leaving dark spaces between. In this case the apparatus is polygonal, and a condensed beam issues from each side or panel. Instead of a lenticular belt all round, each panel has an annular lens with concentric refractors. All the rays falling upon the inner surface of this lens are refracted, and issue as a condensed and independent beam for each panel. The upper and lower prisms in each panel are curved so as to coincide with the concentricity of the central lens. The rays being squeezed or condensed into bundles, dark spaces are left between them. On the whole glass apparatus being made to revolve, beams of light striking the sea area within the horizon, followed by intervals of darkness, succeed each other with regularity.

The flame of Fresnel's 4-wick burner is the basis of our present dioptric system. Six orders of lights were instituted in Fresnel's time, the first order being specially adapted to the dimensions of the 4-wick flame, so that the lenticular instrument should receive all the rays emitted from such a flame. For second order lights, the dimensions of the flame of a 3-wick lamp determined the radius, focal distance, &c., of the lenses employed, and so on. But since that time the 6-wick burner has come into use, 7, 8 and 9-wick burners are on the threshold, and nearly all Mr. Wigham's gas burners, as well as those of Sir James Douglass, have larger flames than Fresnel's 4-wick oil burner. Again, the electric light, with a smaller luminous centre than Fresnel ever contemplated for a lighthouse illuminant, has come into action, so that in point of fact, the orders of apparatus as established by Fresnel, are not adapted to the large and small flames used at the present day. This anomaly is in a fair way of being set right, for Messrs. Stevenson, the eminent lighthouse engineers of Edinburgh, have recently designed a lens of larger radius adapted to an illuminant of increased diameter, and have obtained some striking results with a single Douglass 10-ring gas burner against biform 108 jets.

It remains for me now to explain to you what were the lenticular arrangements employed to give the best results for each lighting system tested at South Foreland. It will be understood from what I previously said, that besides the single light of each system, provision was made for showing the electric light in biform and triform arrangement; that gas could be exhibited in biform, triform, or quadriform; and that oil was provided to show biform and triform only. Consequently, for the electric and oil lights three sets of lenses were required to be mounted in each lantern, and for the gas light four sets were necessary. By the term sets of lenses, I mean one lens arrangement for exemplifying a fixed light, the other for showing the condensed beam of a revolving light. Lenses being very costly articles, it was necessary to have certain regard to economy, consistent with an effective illustration of the value of lenses in connection with the lights to be exhibited. Therefore, one panel only of a fixed belt, and one annular lens of a revolving apparatus, without upper and lower prisms in any case, were provided for each light of each system, the quality of the light issuing from a portion of the apparatus being exactly the same as though the entire apparatus were employed, the only essential point being, that in judging the value of the light, the observer should take care that he is in the path of the beam.

The three towers which were erected at South Foreland for the exemplification of the three systems, were 180 feet apart, and marked respectively A, B, and C. A was appropriated for the electric light; B for the gas system as developed by Mr. Wigham; and C for the oil system and the Douglass gas burners.

In lantern A there were three electric lamps on three stages, and for each lamp was provided a panel of a fixed apparatus of the second order, consisting of a segment of the central belt with seven smaller segments above it and seven below it. The chief reason for using the second order apparatus appears to be that, as Sir J. Douglass practically observes, it affords just enough space for a fairly fat light-keeper to get inside and manipulate the lamps. A third, or even further order apparatus, would have been sufficient, although the luminous area has considerably increased, since the early days of the electric light, where carbons of small sections were used. For exemplifying the revolving beam, an exactly similar panel was used for each light to condense the rays vertically, and in addition four vertical refracting prisms were fixed on the outside of this panel, and caused to issue a condensed beam of great power. It may here be mentioned that, as the divergence of this beam horizontally was very small (30° condensed to 5°), it was necessary to take precautions to insure observers being in its path. In the superposed arrangement the distance separating the three lights was 7 feet, and the space between the lenses 4 feet.

In lantern B the four lights had each panels for exemplifying a fixed and revolving light. For the former, each light was furnished with a segment of the lenticular belt of a first order apparatus without upper and lower prisms. For the revolving light, four first order lenses of annular construction were supplied, each subtending a horizontal angle of 60°. The beautiful lenses of French manufacture were very considerately lent for use in the experiments by the Commissioners of Irish lighthouses. They were intended for and are now fixed up at the lighthouse on Mew Island, coast of Ireland. It should be observed that the four gaslights themselves, being much closer to each other than the three electric lights, the lenses were brought much nearer to each other, and instead of the wide spaces of four feet as between the electric lenses, the fixed gaslight lenses were not separated by more than half a foot, and the revolving lenses were practically joined together, forming a continuous mass of glass nearly 17 feet high.

In lantern C three segments of a lenticular belt, similar in all respects to those in the gas lantern, were mounted for the fixed light, but owing to the great distance apart of the oil burners, the lenses were separated by distances of three feet, which naturally told against the pillar of oil light in comparison with that of four compactly fitted gas burners, shining through four lenses practically not separated. In the revolving light an endeavor was made to compensate for this defect by the use of lenses of larger vertical section, such as are employed at the Eddystone. With these larger lenses, made by Chance Bros., of Birmingham, the outer rings were of flint glass, which has a higher refractory index. The horizontal dimension and the focal distance of these lenses were the same as those in the gas tower. The height only was different, it being apparently sought to make up by lens-power or lens-area, for the want of a fourth light.

This completes the three divisions I ventured to make at the commencement of my paper, and it will be evident to all that very careful and elaborate arrangements with the aid of burners and lenses have been made in each case to get the most out of each illuminant, and to exemplify each lighting system effectively at South Foreland. But the value of a lighthouse illuminant is not reckoned solely by the brightness with which it shines through the darkness of night. For clear weather the lights of ordinary power were and are sufficient for the use of the mariner, provided a sufficient individuality be given to each by which it can be readily recognised. The whole purpose of developing these larger and more powerful lights is to overcome the resistance offered to the passage of light rays through the atmosphere, by the obstructing medium of watery vapor in its various gradations from thin haze to thick fog. The times have long gone by when merchant ships would anchor if even a small fog appeared; now-a-days maritime traffic round our coasts stops for nothing. Sound fog signals have become a necessity of the times, to be sounded so soon as the effectiveness of lights is seriously impaired by a thickened atmosphere. But it is very desirable that the lights should hold out as long as possible; that though the effect of a haze might be to lessen the range of a light, yet that its rays should penetrate sufficiently through the haze to be of some practical service to the mariner, to be seen by him in time to prevent his running into danger, or to guide him on his way. If any one illuminant is proved to be able to cope more successfully than the others with this obstructing medium, that light can certainly claim to be superior for lighthouse purposes in thick weather. This, then, is the great problem which is to be solved; which of the three systems, oil, gas, or electricity, when exhibited under the most favorable conditions, has the greatest penetrative power in thick weather? And in connection with the solution of this problem it will be found that considerations of economy and convenience cannot be dissociated from the question.

It will, doubtless, be evident that the question of the relative merits of lighthouse illuminants is considerably more complicated than the general public think it is. We have seen what is the nature of the competitive illuminants, and how they are dependent on burners and lenses to make them serviceable for lighthouse purposes; also how they were exemplified in A B and C towers at South Foreland. We are, therefore, better prepared to enter upon the direct consideration of the actual trials.

A few words may here be interpolated regarding the personal arrangements for carrying out the experiments.

Upon the dissolution of the Illuminants Committee, for reasons which need not be discussed here, this tangled question was by the Board of Trade referred to the Corporation of Trinity-house, who accepted the responsibility of carrying out the investigation, seeing that a great deal of public interest had been drawn to the question. A Committee was formed of members of the Corporation, consisting of Captain Sydney Webb, the deputy-master, as chairman; Captain Nisbet, Captain Weller, Captain E. A. Vyvyan, Captain Burne, Admiral Sir Leopold McClintock, and Mr. John Inglis, secretary to the corporation; to this committee I had the honor of being appointed secretary. The first thing done was to obtain the friendly co-operation of the Scotch and Irish Lighthouse Boards, and it is only proper to state that such co-operation was most cordially extended by both Boards and their officers to the Trinity-house Committee. The Committee had the great advantage of frequent personal communication with Mr. Thomas Stevenson, the eminent engineer to the Scotch Lighthouse Commissioners, and with Sir Robert Ball, the Astronomer-Royal of Ireland, and Scientific Adviser to the Commissioners of Irish Lights. They also invited, and were fortunate enough to secure, the aid of Professor W. Grylls Adams, F.R.S., of King's College, London, and Mr Harold Dixon, of Balliol College, Oxford, the former for advice and assistance in respect of the electric lighting apparatus, the latter for aid in carrying out the necessary photometric observations on the various lights to be exhibited. In addition they had the great advantage of frequent consultations with Mr. Vernon Harcourt, F.R.S., of Trinity

College, Oxford, who watched the trials on behalf of the Board of Trade, and whose knowledge of photometric work is probably unequalled in this country; further, the invaluable practical experience and profound knowledge of lighthouse experiments of Sir James Douglass were at all times available, and the suggestions and opinions of representatives of foreign lighthouse authorities were cordially given and received.

It was in full view of all the world, and specially all who were in any way interested in the subject, that the experiments were commenced and carried through; the whole arrangements were open to the fullest and freest public inspection. It is essential to make it quite clear that the Trinity house Committee courted inquiry, suggestion, and inspection. They only desired to arrive at a just decision; and I, as secretary to that Committee, and with all respect to those who may have been inclined to think otherwise, venture to challenge anyone to prove the contrary.

The South Foreland station was selected for the trials because of the existing facilities for observations on land and at sea, and because there was a sufficient reserve of steam power, over and above that required for the machines feeding the permanent lights, to operate the additional electric machines. The land in the neighborhood of South Foreland is undulating, but has no hedges and few trees, and therefore affords facilities for observing the lights at distances of between two and three miles.

It may be assumed that the three lighting systems were adequately represented by the apparatus set up at South Foreland; the arrangements for exempllying the electric and oil systems in A and C towers, were made under the immediate direction of the Trinity-house Committee and their engineer, Sir James Douglass. The exemplification of the gas system was left in the hands of Mr. Wigham to arrange, as he thought best, for the exhibition of his quadriform light. It is true that the Committee demurred to making trial of what Mr. Wigham called his double quadriform, *i.e.*, two sets of four lights placed side by side in the lantern, which he urged upon them, they not having any practical experience of the effect of burning eight large gas flames in a lighthouse lantern for several hours, nor could they learn that the Commissioners of Irish Lights had had any such experience. With this limitation only, Mr. Wigham had perfect liberty to show the best light he could produce with four large burners placed vertically his foreman, Mr. Higginbotham, might use as much or as little gas as he thought proper; he might regulate his draught as he liked; he had the gas manufacture under his own supervision, and made as much, or as little as, and of what quality, he pleased; the cannel coal was specially selected by Mr. Wigham, and no restriction of any kind was placed upon his foreman as to the mode of keeping up his light. He was simply required by the Committee to show a certain light at a certain time, in order that it might be compared with another light, and it was entirely his own business how he produced that light. He was not controled in any way whatever, and I can testify that it was through no default on the part of Mr. Higginbotham that the gas light did not outshine the most powerful electric beam. Mr. Higginbotham's mechanical ingenuity always being applied to improve the gas-light, and his devoted loyalty to the interests of his employers, were noticeable points in connection with the gas-light exhibition. A Trinity-house lightkeeper was on duty in this lantern, but he had no power to interfere with Mr. Higginbotham's management of the light. It should also be mentioned that the electric and oil towers were manned by Trinity-house keepers, over whom, as well as over the whole experimental establishment, Mr. J. Sparling, the very intelligent engineer in charge of the South Foreland permanent station, exercised a general supervision, subject to the members of the Committee, who it was arranged should be constantly on the spot.

OBSERVATIONS.

Assuming all the necessary arrangements to have been made for exhibiting the various lights at the South Foreland, the next matter for consideration is how they were observed. It was resolved that two kinds of evidence should be obtained in reference to the relative merits of the illuminants, as shown, the one of a practical nature from competent eye witnesses at various distances, the other of a more scientific or expert character. With regard to the former, it may be stated that from the lightsmen on board the Gull, the Goodwin, and the Varne light-ships; the pilots and masters of vessels navigating in the vicinity; the Elder Brethren of Trinity-house and their officers; the coastguardsmen between the South and North Forelands; valuable data were obtained respecting the relative merits of the lights in different kinds of weather, and at various distances, from one to twenty-four miles. In addition to the observations so made at sea and on land, special watchmen were detailed to observe the lights nightly at shorter distances, along a line marked off by posts 100 feet apart, and running across the country for a total distance of two and a-half miles, all the competing lights being fully visible in clear weather along the whole length of this line. Three huts were set up along this line—No. 1 at a distance of 2,144 feet, or nearly half a mile from the lights; No. 2, 6,200 feet, or nearly one and a quarter mile, and No. 3 at the extreme point, two and half miles. The night walks along the lines, the blinding effect of the lights, and the welcome shelter in the huts, will, doubtless, be remembered with interest by many of the visitors who joined the observing parties. This short range was very serviceable on nights when haze or fog prevailed, it being possible to measure with a very fair approximation to accuracy the distance at which each light was observed. The observations made were recorded in books specially prepared for the purpose, on a uniform system; thus all the returns were made in the same way. The instructions were as follows:

INSTRUCTIONS TO OBSERVERS.

The lights to be observed will be shown from three towers in a line bearing N.W. from the permanent high lighthouse, and will be identified by means of the letters A, B, and C respectively.

When possible, observations of the three lights should be made at each hour from 8 P.M. to midnight.

In recording an observation, put down in the A column the light from the A tower as 100, and in the corresponding B or C column put down the number as compared with 100, which represents the difference in power. Thus, if *B* appears to be twice as good as A, and C appears to be only half as good as A, the record should be A 100, B 200, C 50. In the columns headed "Place of Observation," it is requested that the position and distance from South Foreland may be stated as accurately as possible at every observation recorded.

The state of the atmosphere each night is to be carefully noted, and recorded in the column provided for the purpose, in one or more of the following terms: Clear; cloudy; very dark; moonlight; hazy; slight fog; ordinary fog; drizzling rain; ordinary rain; heavy rain; snow; hail; sleet. Each night's record to be signed by the observer, the place of observation being in every case clearly indicated.

Remarks of a special nature concerning the appearance of the lights are to be made on the fly-leaf provided for the purpose. Under this heading observers should record any apparent difference in the color; any apparent unsteadiness, variations, or obscurations of the lights; also the effect of the lights upon the clouds: and, where a fair comparison is possible, of the relative value of other lights in the vicinity, those on the French coast, for example.

The other kind of evidence sought to be obtained was that of the scientific measurement of lights by the most approved photometrical methods. These operations were carried on at the three huts before mentioned, and in a dark gallery 380 feet long, specially constructed for the measurement of large and powerful lights. This portion of the investigation was mainly in the hands of Mr. Harold Dixon, who had the advantage of frequent communication with Mr. Vernon Harcourt on the subject, and able assistance in carrying out his work from Sir James Douglass, Messrs. Lyle and Longford (who at Dr. Ball's suggestion were sent to South Foreland as the representatives of the Irish Lighthouse Board), and Mr. Sparling. All the various lights exhibited were subjected to measurement, both as naked flames and as shown through lenses, the value of each being expressed in numbers of candles. For these measurements the Harcourt pentane standard flame, adjusted to correspond with accuracy to the average flame of a number of sperm candles, was chiefly employed; but occasionally a portion of the flame of a mineral oil Douglass burner, enclosed in a square iron-sided lantern, was used. A small opening in one side of this lantern was fitted with a Methven screen, so adjustable that the rays passing through the opening would represent $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, or other convenient candle-power, as might be desired, in accordance with the single flame of the pentane standard. A portable pentane lamp was generally used in the huts, but on windy nights the Douglass flame was found to be very serviceable, being less sensitive than the unprotected pentane flame. In the photometric gallery, a standard pentane flame in connection with a complete apparatus for making the gas on a sufficiently large scale was available. Without going into detail respecting the manufacture of the gas and the special merits of the pentane standard of light, I may here record the fact that with its aid a great deal of valuable and trustworthy work was done.

Although I do not propose to enter upon a detailed consideration of the photometric methods employed by Mr. Harold Dixon and Mr. Vernon Harcourt, the subject being one which could not be adequately discussed in the space of time at my disposal, yet some remarks of a general character may be made upon the subject.

Let me first say, for the benefit of those to whom photometry is a dark study, that the standard light is that in comparison with which the light under test is to be measured. The value of this standard light is expressed in candle-power.

At South Foreland the naked lights were measured in the photometric gallery, and the lights through lenses at No. 1 or No. 2 hut. The principle mostly adopted with the former was to cause the light of the standard flame to fall on one side, and that of the light under measurement upon the other side of a movable screen with a translucent star disc in the centre. By moving the screen to and fro along the graduated bar, a position could be found where the stars would show with equal distinctness on both sides of the screen. In such circumstances, the illuminating power of the burner under measurement would be directly as the squares of the distances between the disc and the burner, and between the disc and the standard light.

A modification of this method was occasionally employed in the gallery, and always at No. 1 hut, distant 2,150 feet from the lights. The light of the standard flame, and that of the illuminant under test, were thrown upon the same side of a disc of translucent paper fixed in the centre of an opaque screen, while, by means of an umbrant or shadow-thrower, contiguous portions of the disc were illuminated by the standard and the distant light. By moving the table nearer to or distant from the standard, a position was found where the illumination in the three divisions of the disc appeared to be equal. By this method direct measurements of all the lights in A, B, and C towers could be made at No. 1 hut.

At hut 2 the bar photometer with the movable star disc was used, but owing to the great distance from A, B, and C lights, 6,200 feet, it was found necessary to condense the light from the distant towers by a small achromatic lens interposed in the path of the beam entering through a circular opening in the window screen. In thus condensing the light, a certain loss by absorption and reflection was experienced, but in all measurements the requisite correction on this account was applied.

In this connection it was feared that the difference of color between the light of the electric arc and that of the standard flame would be a serious difficulty, and would prevent an effectual comparison being made as to relative illuminating power of the different colored lights. But Mr. Dixon says " that with the use of the star disc no such difficulty was felt. Equality of distinctness in the pattern of the star on both sides of the disc could be judged without difficulty, although both star and back ground appeared of complementary tints on the two sides. Since the object of the investigation was to determine for each illuminant the total quantity of light which affected the eye and conferred visibility upon the lamp, independently of its color, the distinctness of a pattern, illuminated by lights of different color, seemed to afford a criterion of their true illuminating power less open to error than any method of striking an average between the illuminating power of separate groups of colored rays filtered from each beam by the interposition of colored media. It was also found that different observers made concordant measurements of the electric light with the star disc."

The lights were exhibited, watched by many observers, and measured by the indefatigable photometrists over a period of twelve months. During that period a large amount of valuable evidence was collected, by the aid of which the committee were subsequently enabled to state their conclusions with definiteness.

RESULTS.

At a comparatively early stage of the trials it was found that no practical advantage was gained by superposing electric lights, but that, for the reasons previously stated, a sufficiently effective result was obtained from one arc fed by two electric machines. This form of light was accepted by the Committee as that best suited for the exposition of the electric system, and that upon which it should be judged in respect of its merits as a lighthouse illuminant.

For gas, the columnar light of the quadriform arrangement, with a burner of 108 jets for each tier, was the highest power available, and was regarded as the best representative of the gas system.

For oil, the Committee had resolved to rely upon the performance of the 6-wick burners, which had been in use in the Trinity-house service for many years; and three of these, mounted in triform arrangement, as has been described, were adopted by the Committee as representing the best effect which could then be produced with the oil system.

It will be plain that for the large flame lights there was ample recognition of the value of the system of superposing, a recognition, doubtless, very gratifying to Mr. Wigham, who successfully developed the system with his gas apparatus, although others may have tentatively preceded him in the same direction. It was certainly proved by the trials that the system possesses some real advantages. But it is very essential that provisions be made to check the radiation of heat from the flue pipes. With the superposed oil burners effectual measures were adopted, but not in the case of gas, consequently with the four great gas lights burning in a lighthouse lantern, the heat generated would be so considerable as to endanger the safety of the lenses, and render the lantern uninhabitable. Mr. Higginbotham, Mr. Wigham's foreman, bore the heat in the gas lantern at South Foreland like a genuine salamander; but there are some lighthouse keepers who would be likely to frizzle and grill under such conditions. I may mention that the temperatures in the lantern, when the four burners were alight, ranged from 180° F, in the lowest tier, to 370 F. in the highest. It was this great heat, taken in conjunction with the cracking of some of the lenses, which influenced the Committee in declining to try Mr. Wigham's double quadriform light, in which eight instead of four burners were to be burned in the lantern. If four burners made the temperature 370°, what would eight burners have done?

A great number of experiments were of course made with the lower powers of the respective illuminants, and information gained which will be of very great value in the lighthouse service; but in stating the results of the trials, it will be sufficient to regard each light as shown at its highest power, viz.: Electric, one light, two machines; gas, four lights, 108 jets; oil, three lights, six wicks.

Clear Weather.—In fine weather it was evident that all the lights were too good, and that for merely sending an effective beam of light to the horizon on a dark clear night, no one was really better than another, although it may be said that the experimental electric light was regarded as a nuisance rather than otherwise by mariners in the near neighborhood of the South Foreland. It is quite certain that for clear weather the lower powers of any one of the illuminants would be sufficiently serviceable for the requirements of the mariner, either as a fixed or a revolving light. This is proved by the reports made by distant observers, who, on a clear night, would record that the single lights were not less effective than the triform or quadriform arrangement. In this connection, *i.e.*, as regards clear weather, the only points really noticeable are in respect of the adaptability of the lights for occultations, one of the distinctive characteristics used for lighthouse lights, and for marking special dangers by means of colored sectors. As regards occultations, it is clear that, although with the electric light a simple arrangement might be devised of breaking contact and renewing it at certain periodic intervals, it would not be accomplished without some risk to the steadiness of the light, and, moreover, would not be worth while, because the generation of electricity would still be going on, and nothing would be saved. In the case of oil, it is not very easy to turn the light up and down to produce the effect of occultation. It it were, some saving in oil consumption might perhaps be gained, but it would be very small. To produce occultation with electric and oil lights it is therefore necessary to employ a simple mechanism, by which a cylindrical screen falls and eclipses the light for the requisite period, and is then drawn up. But with gas, the turning off and on of the supply is sufficient to produce occultation in an economical and effective manner. This is certainly a point to the credit of the gas system, but its effective application is limited to fixed lights, for it is questionable whether this kind of occultation can be applied with success to flashing or revolving lights.

For colored sectors it is necessary that the limiting radii should be as sharply defined as possible, that mariners may know immediately they go over the border line. With large flame lights, the border lines are not clearly defined, but instead are found areas of uncertain light of varying width. With the electric light this width is only a few feet at a distance of 1¼ mile; with the gas light at full power it is over 140 feet at the same distance; and with the oil light at full power it appears to be between 50 and 60 feet. The changing of the points of incandescence in the carbons causes the electric light line to move within a range of 15 feet, but the line of definition is always sharp. The width of the uncertain light increases in proportion to the distance, and it is consequently of importance to obtain the sharpest possible definition of the sector. Electric, for this is certainly the best, the oil system, with 6-wick burners, being a good deal better than the gas system with great 108-jet burners.

Haze and Fog.—We now come to the question of haze and fog.

The gradations of atmospheric transparency are numerous, and it is between such extremes that the mariner finds powerful lights specially useful. It is when the atmospheric transparency is impaired more or less that these strong lights are required. It is very difficult to graduate the opacity of the atmosphere, but for our purpose it will be convenient to separate weather which in a general way is misty or hazy from that which is essentially foggy.

The general result of all the observations made in respect of haze, show incontestably that the single electric light, as shown from the A tower, greatly excels the most powerful superposed gas or oil light in penetrating power, either as a fixed or revolving light. Of 284 eye observations recorded as made in weather not clear, but without actual fog, the mean percentage of superiority of the electric light over gas is about 36, and over oil, 41. These percentages must not be taken literally, they are not intended to convey exact numerical ratios, but are founded upon the estimates of many and various observers at different positions, and possibly under different conditions. But the general verdict of superiority of the electric light in such conditions of weather is plain and unmistakable. It is always better than anything else.

As regards gas and oil, 231 observations of quadriform gas, 108 jets revolving, as compared with triform oil 6 wicks revolving, made at times when the transparency of the atmosphere was impaired by mist, haze, rain, or snow, show that the gas light has a mean percentage of superiority 5.8 per cent. When shown as fixed lights, the superiority of gas over oil is increased to 12.2 per cent. as the mean of 72 observations. In this case the body of miscellaneous observers give their verdict that the gas light is better than the oil light. This advantage does not mean that the revolving gas light penetrates to a greater distance than the revolving oil light, but merely that at the points of observation, near or far, where both are seen, the gas light is regarded as better than the oil light. But, for all practical purposes, the oil light is seen whenever the gas light is seen, although it is evident that the gas is the better light of the two, as it ought to be with its four lights against three. As a fixed light, the gas certainly has the best of the oil. The four closely packed 108-jet gas flames showing through their closely-fitted lenses, yield a column of light very superior to that of the three widely separated 6-wick oil lights. As exemplified at South Foreland, the oil light was beaten by the fixed gas light. But without stopping to inquire whether a better effect could have been made with the fixed oil light it may be said that fixed lights are gradually becoming of less importance, owing to the necessity for providing lights with distinctive characteristics, for condensing the rays into strong beams, and to avoid lighthouse lights being mistaken for anchor or other lights on board vessels at sea.

In actual fog the electric again holds its own. The experience of fogs at South Foreland, though not large, was sufficient to furnish valuable comparisons, and it was proved beyond question that the single electric light pierced a greater depth of fog than the highest powers of either gas or oil. The quadriform gas and triform oil lights were practically equal in fog, though some observers occasionally recorded the gas as a few feet better. But in such fogs the mariner would not derive the slightest advantage from any light. The recorded distance to which lights were carried, or where they were picked up in the fog, range mostly between 700 and 2,000 feet from the lights themselves, and the superiority of the electric light is determined by its penetrating 200 or 300 feet further than the gas or oil lights. The most powerful electric light was shut out on one occasion at 1,450 feet, on another at 1,500, another at 1,700, on another at 1,500, another at 1,300 feet. It will be plain to all here that no mariner could possibly be benefited by a light which was not visible at such distances from the lighthouse. And for purposes of navigation a difference in the visibility of the lights of 200 or 300 feet is of no value whatever. One remarkable fact stands out prominently here, viz., the greater ratio of absorption by the fog of the electric rays as compared with the gas and oil rays. Fortunately for the electric light, as shown at South Foreland, it possessed a large reserve of initial intensity, which enabled it, notwithstanding its much greater proportion of loss by absorption of its more refrangible rays, to penetrate further than the other illuminants. With three lights of equal candle power, one electric, one gas, one oil, exhibited in a foggy atmosphere, there is little doubt that the electric would be eclipsed at a much shorter distance than the others; but as the electric beam can be made so much more intense than it is possible to make the gas or oil beam, the electric light, though heavily handicapped, beat its competitors in fog by the superabundance of its own luminous energy.

Such, then, are the results obtained from the testimony of eye witnesses. The photometric measurements entirely corroborate the eye observations as to the superiority of the electric light in all weathers, both in revolving and fixed phase. They also give the 108-jet gas burner a superiority over the 6-wick oil burner, when both were shown through similar lenses; and, taking the mean of all weathers, the former is credited with an advantage of 16 per cent. over the latter. But it is important to note Mr. Harold Dixon's remarks on this point. He says "this difference in illuminating power means but slight difference in penetrating power. In many observations, both on sea and land, in haze and in thick fog, the quadriform 108-jet gas light was picked up just before, but only just before, the triform 6-wick oil light; in other observations the two lights were picked up simultaneously." This exactly coincides with the evidence of the eye witnesses, and supports the belief that the four lights in the gas lantern just managed to hold their own and no more against the three lights in the oil lantern.

The table in page 505 gives the value of all the burners in clear weather. The results are stated for a single burner in each case, but to obtain the value of quadriform gas or triform oil it is only necessary to muliply by four or three.

The experiments have shown clearly that, light for light, *i.e.* diameter for diameter, gas and oil are very much alike in illuminating power; indeed, under such conditions, the oil flame seems to be rather the better. They have also shown that oil lights can be superposed with the same facility as gas lights, and can be exhibited under similar conditions, with one exception, that no oil flame has yet been brought to the enormous size of the 108-jet burner. But as this enormous size of flame is not required, this

TABLE OF PHOTOMETRIC VALUES.

Name of burner.	Dimensions of the flame.			Illuminating power in candles (mean results).			
	On the burner.	At focal plane.	Height.	Naked flames.	Through lenses in clear weather: Cylindr. belt.	Eddystone.	Mew Island.
	Inches.	Inches.	Inches.		Fixed light.	Revolving light.	Revolv. light.
6-wick oil, Douglass, old pattern	$4\frac{3}{4}$	$4\frac{3}{8}$	5	730	5,000	64,000	48,000
7-wick oil, Douglass, new pattern	$5\frac{7}{8}$	$4\frac{3}{8}$	6	947	8,100	60,000	49,000
8-wick oil, Douglass, new pattern	$7\frac{1}{2}$	$5\frac{5}{8}$	$6\frac{1}{2}$	1,400	..	..	..
9-wick oil, Douglass, new pattern	$7\frac{1}{2}$	$5\frac{5}{8}$	$6\frac{1}{2}$	1,785	..	..	..
6-ring gas, Douglass (cannel)	$4\frac{3}{8}$	$2\frac{7}{8}$	5	825	6,700	92,000	70,000
10-ring gas, Douglass (cannel)	$7\frac{1}{2}$	$5\frac{5}{8}$	$6\frac{1}{2}$	2,500	12,899	105,000	94,000
108-jet gas, Wigham (cannel)	$11\frac{1}{4}$	$11\frac{1}{4}$	13*	2,300	15,600	..	59,000
88-jet gas, Wigham (cannel)	$9\frac{1}{2}$	$9\frac{1}{2}$	13*	1,400	13,000	..	54,000
68-jet gas, " "	$7\frac{3}{4}$	$7\frac{3}{4}$	13*	990	8,800	..	48,000
48-jet gas, " "	6	6	12*	689	5,700	..	42,000
28-jet gas, " "	$4\frac{1}{4}$	$4\frac{1}{4}$	12*	250	3,000	..	33,000
Regenerative gas, Siemens (cannel)	10	10	6	600	3,300	10,000	..
Regenerative gas, Siemens, small size (cannel)	4	4	4	194	..	..	..
6-ring gas, Sugg (cannel)	$7\frac{1}{2}$	$7\frac{1}{2}$	$8\frac{1}{2}$	824	5,600	55,000	..
						Cylindr. belt with vertical prisms. revolv. light.	
Electric, 1 machine	..	..	..	10,000	120,000	1,250,000	..
Electric, 2 machine	..	..	..	15,000	150,000	1,500,000	..

* 4½ to 5 inches of these heights are naked flames, the remainder is surrounded by a transparent talc chimney.

is not of great consequence. As the two lights were shown to be so nearly equal, the questions of convenience and economy assumed very considerable importance in connection with their relative merits as lighthouse illuminants. It had to be considered that the gas system could not be taken to a rock lighthouse or used on board a light vessel, therefore its application would have to be limited to lighthouses on the mainland. The necessity for the erection of gasworks, gas-holders, mains and pipes, &c., involved a large expense, all of which might be justifiable if the advantage to be gained were proportionate. But, on the other hand, mineral oil was found to be so cheap, so easily supplied and stored, and so easily managed, that the balance of advantage was seen to be distinctly in its favor. Here is the real enemy which has beaten the gas system. As I before observed, the arguments employed in the early part of this discussion to demonstrate the economy of the gas system were based on the then prices of rape seed oil at 4s. 9½d., 3s. 10½d., 2s. 9d. per gallon, but times are changed; mineral oil has now replaced the high priced rape seed oil, and is supplied at 6d. per gallon. It is this fact which has demolished all elaborate computations to prove the economy of gas. Notwithstanding Mr. Wigham's great ingenuity and perseverance, circumstances over which he has no control have vanquished him; and if at any time Mr. Wigham can bring down the price of coal gas so that the light is less costly than that of mineral oil, he may reasonably expect that oil will then have to take a back seat. But that time is not yet.

The whole result may be approximately stated as follows:—For expenditure of raw material only, without reference to plant, labor, &c., a 6-wick mineral oil lamp burning for six hours would consume four gallons of oil at 6d.=2s., or, say, 3s., including wicks, cylinders, &c. A 108-jet burner alight for the same period would consume 1,800 cubic feet of gas, at a cost of not less than 10s. for coal alone. Taking all these considerations into account, it will not be surprising to this audience to hear that the final conclusion of the committee was:

"That for ordinary necessities of lighthouse illumination, mineral oil is the most suitable and economical illuminant, and that for salient headlands, important landfalls, and places where a very powerful light is required, electricity offers the greatest advantages."

DISCUSSION.

The Chairman, in opening the discussion, pointed out the thorough manner in which the testing of the lights in the experiments spoken of had been carried out over long intervals of time, and under a variety of circumstances. No doubt, therefore, could attach to the conclusions arrived at. From a practical point of view, one of the most interesting results was the short distance penetrated by the most powerful lights, and it seemed that a doubling or trebling of the lights in many cases very little increased their power of penetration through fog. Perhaps, after all, that was what might have been expected, for when powerful lights of many thousand candles were entirely quenched at the distance of a few thousand feet, it was evident that in every few hundred feet of that distance the lights must be diminished in considerable proportion. Further particulars as to the less penetrating power of the electric light as compared with oil or gas would be interesting. To a certain extent people were misled by ordinary London experience of fogs. It was a matter of common observation in London, a few years ago, when the electric lights were burning on the embankment, that at a very moderate distance they seemed to be almost as red as the gas lights burning beside them, but that effect was more likely to be produced by the London smoke rather than by what could be properly called fog. When the sun at midday is shining through a bank of cloud which allows its line to be visible, it is seen, not altered in color, but in its original whiteness. At sunset, it was true, when the sun shines through a lower stratum of the atmosphere, a red color is perceptible, but that appearance could not properly be attributed to fog or cloud, otherwise the same effect would be observed when the sun was high in the heavens, and its rays had to pass through a mile or a mile and a half of cloud. A little more than a year ago he had himself witnessed the experiments with these lights, and had spent a very interesting night walking between the huts spoken of, placed at various distances from them, and in observing the effects of the lights, and the careful arrangements made with reference to photometry. As to the comparison of the effect of lights of different colors, he saw the star-disk arrangement spoken of in the paper, and had verified the possibility of taking very accurate observations in spite of difference in color between the electric and gas and oil lights. Within the last week Captain Abney and General Festing had brought before the Royal Society a very interesting account of some elaborate observations which had been made upon this very subject of the photometry of different colored lights, and they had proved (rather to the surprise of many) that it was possible to make comparisons between lights of very various colors, between white light and the green, or red lights and the spectrum, almost as accurately (Captain Abney said, within 1 or 2 per cent.) as could be done between lights of absolutely the same color. In estimating the rapidity of the alternation of the currents, Mr. Edwards appeared to have multiplied the number of coils by the number of revolutions, assuming that each coil sent a distinct pulse. He thought the arrangement was such that each passage of the coils in front of the magnet page one pulse, so that the number of coils should not be multiplied by the number of revolutions to obtain the number of pulses. He scarcely thought that the number of pulses could be so many as over a million in a minute, as had been stated, but some of the gentlemen present would probably be able to speak upon that point.

Professor W. G. Adams, F.R.S., said that, from his own personal observations and measurements, he could bear Mr. Edwards out in many of the remarks which he had made with regard to the relative illuminating powers of gas and oil, and of the electric light, under the arrangements for their comparison which were made at the South Foreland. As regards the comparison of oil and gas, he thought Mr. Edwards had given a full and fair account of their relative merits, and had drawn just conclusions on them. He would strongly emphasize the praise of the Douglass 6 and 10-ring gas-burners, for he felt sure that all who had the opportunity of judging must be of opinion that for the compactness of the burner, the concentration and steadiness of the flame, and for the remarkable economy of gas, these Douglass gas-burners far surpassed any other gas-burner which had ever been tried for lighthouse work. The 6-ring burner, 4½ inches in diameter, gives the light of 108-jet gas, 11¼ inches in diameter, and only consumes one-third of the amount of gas consumed by the 108-jet burner. The 10-ring Douglass gas-burner, 7½ inches in diameter, gives 60 per cent. better light, and only consumes two-thirds of the gas of the Wigham 108-jet burner. The relative smallness of these flames is of great importance in their use behind a lighthouse lens. And here he would draw attention to a fallacy which seemed to exist in certain quarters, and from which Mr. Edwards did not seem to be quite free, but which had been fully proved to be a fallacy by the experiments at the South Foreland. It is assumed that a second order lens, or even a third or a fourth order lens, is quite large enough for a source of light of small size like the electric light. The results, as given by Mr. Edwards, have shown that if the object was to prove the superiority of the electric light over any other light for lighthouse use, then the second order lens was quite sufficient to show this superiority under any conditions of weather. As long as oil and gas flames were of moderate size, say four inches in diameter, second order lenses did fairly well; but when flames 6 or 8 inches in diameter came into use, there was found to be little or nor increase in the light, and so the lenses too must grow, and we must have Fresnel's first order lenses. Then, again, the flame grows to 10 or 11 inches, and even first order lenses give very little increase over smaller flames, as shown by comparison of Wigham 88-jet and 100-jet gas in Mr. Edwards' table; and so it becomes necessary to construct a lens, as Mr. Stevenson has done, which considerably exceeds in size what has hitherto been called "the first order lens." The experiments at the South Foreland have shown, and Mr. Edwards' table proves it, that lights concentrated into a smaller focus, and especially electric lights, gain more than any others by the use of larger lenses. Compare the Douglass 6-wick oil (730 candles), the Wigham 68 jet gas (990), and the Douglass 6-ring gas (825), when used behind the same Mew Island lens. Much more is this the case with the electric light. Had Mr. Edwards completed his table, and given the illuminating power of the electric light through the Mew Island lens, as given in his (Professor Adams') report, the numbers, 15,000,000 and 18,000,000, would have been seen in the last columns of that table as compared with 59,000 for the 108-jet gas. The multiplying power of the lens for the electric light would have been 1,500, whereas for the 108-jet gas it is only 25, and about 38 for the Douglass 10-ring gas. It will be seen that, with the cylindrical belt with vertical prisms, the multiplying power for electric light is 125, and for the Mew Island lens it is twelve times as great, or 1,500. For the adequate comparisons of the electric light with other systems of lighthouse lighting, it is essential that the same lenses should be used, and for this as well as for some other reasons, we must look upon the results of the South Foreland experiments as only showing that the electric light is superior to every other light, but not by any means as showing what the electric light is capable of doing. His (Professor Adams's) report showed that much more has been done, and that under favorable conditions far more of the electric energy can be converted into light-giving rays. The merits of the electric light as a lighthouse illuminant cannot, as his report showed, be arrived at simply by the results as shown from the A tower at the South Foreland, without taking into account the loss of energy to which Mr. Edwards had alluded, and which would not exist in any permanent installation. With regard to these experiments, he (Professor Adams) had been asked by practical men how it is that so little light as 10,000 or 12,000 candles is obtained from the expenditure of so much energy, when we get more efficiency and far more effective work from our dynamo machines. To some extent this is true, and may easily be accounted for. A machine does most effective work when the external resistance of the circuit is not greater than the internal resistance of the machine; now in this case the internal resistance of the De Meritens machine is .05 ohms, and the resistance of the leading wires to the tower (to say nothing of the lamp and the electric arc) is .077 ohms, or more than half as much again. Hence it will be evident to all practical men that these excellent De Meritens machines can do far more than has hitherto been done with them. Whereas the light in the A tower is given by a current of 100 amperes, or at most 130 amperes, the machine has given a current of 420 amperes when the electric lamp was not far away from the De Meritens machine. With regard to the apology of Mr. Edwards, or the reason he alleges why the electric light has not been used in England, although it has been received more favorably in France (on the French coast there are 42 electric lights), he would ask if the mariners ever object to the dazzling brightness of the sun, and if the electric light does not more nearly resemble brilliant moonlight? Mr. Edwards said the electric light was removed from Dungeness, because mariners disliked it, but he (Professor Adams) had shown in his lecture at Aberdeen, before the British Association, what mariners thought of the electric light of the South Foreland when it was first established there; he quoted from a work of M. Petit, translated by Mr. Edwards. M. Petit says: "The advantages of the system have been highly appreciated by mariners, and the increase of range of the lights has been very marked in slightly foggy weather. It certainly enables mariners to continue their voyage, and to enter a port at night, when they would not have been able to do so with oil lights." M. Petit for many years was commander of a steamer on the postal service from Ostend to Dover. To M. Petit's paper, and to his (Professor Adams) report to the Trinity House, as well as to his lecture at Aberdeen, he must refer for proof that the step from oil lights of 1870 to electric light of 1884 represents an improvement in the proportion of from 30 per cent. to 90 per cent. in lighthouse illumination, and that the number of nights on which the electric light is seen 20 miles away is about 90 in every 100. On a few very thick nights an increase of 100-fold in the source of light, whether it be electricity, gas, or oil, will hardly increase the distance to which the light is seen by 100 yards. He thought Mr. Edwards must have made a mistake in his description of the mode of coupling the machines. The two machines coupled parallel have an E.M.F. of 60 volts, and a current of 176 amperes, and the two machines in series are said to be also of 60 volts, and a current very nearly the same; these values seem to show that in this case the coupling must have been also parallel, probably the opposite poles of the magneto machines were connected. He was glad to hear of Mr. Edwards state that the electric light can generally be maintained with a fair amount of steadiness, and that the fluctuations have not been very serious, but I think no friend to electric lighting can ever hold with him that its unsteadiness may be advantageous. As regards the size of lenses used in the A tower, they extended only over 30° of arc, bringing the bundle of rays into a parallel beam, whereas the Mew Island lenses in the B tower extended over 60° of arc, both horizontally and vertically. With regard to the greater absorption of the electric beam by the atmosphere, the experiments with steam fogs had shown that it was by no means so great as was previously supposed. The illumination given by the blue and violet rays is very small, and even if they were absorbed, the total light would not be thereby very much reduced. The experiments at the South Foreland have shown that, using the large Mew Island lens, with the 108-jet gas of 2,400 candles, and the electric light of 12,000 candles with the smaller lens, the electric light in clear weather was at least sixteen times as bright, and in foggy weather was about thirteen times as bright as the gas light, the excess of absorption for the electric light being about 20 per cent. more in foggy than in clear weather. Had the same lenses been used for both electric light and gas, the illumination given by the electric light would have been from 150 to 200 times the light from gas.

Professor C. Vernon Harcourt, F.R.S., said one of the points of most general importance was that raised by the Chairman as to the relative absorption of the electric and of other lights by the atmosphere in a certain condition. It might be that one of the causes why the electric light was credited with suffering more by atmospheric absorption was that so many observations were made in London, and that London fog differed perceptibly from such haze and mist as was met with at sea; and it might differ in respect of possessing this selective absorption in much greater degree than when the air was simply obscured by suspended particles of water. When there was rain falling, or there was a wet fog, such as was met with sometimes on ascending a mountain, the obstruction to the light was suffered equally by light of all degrees of refrangibility, and it might be that when the water was more finely divided, as in a haze, that this selective absorption occurred where the size of the globules was comparable with the wave-length. He was glad to hear Professor Adams' remarks as to the degree to which absorption reached. Becquerel stated that for solar light the rays from blue to violet were 14 per cent. of the whole; but it had been stated that the proportion of these rays was greater in the electric light than in the solar light; and perhaps in that case the total absorbed in this selective way might be more than 14 per cent. It was very important to have some such limit fixed to the possible loss of light in this way. It was also important to understand that the way in which the atmospheric absorption acted was, as Professor Adams had described, that each stratum of thick air which the light passed through, cut off a certain fraction, and that the same abstraction happened to all light of the same color, and was of such a character that there might be a great disproportion between the increase which might be produced in the light and the cone of rays which was the consequence of that increase. If the fog were such that one of Mr. Wigham's single lights were extinguished at two miles, the quadriform light would only extend to 2.1 miles, or something like that. Sometimes expressions were used as if it were possible to produce light of such a kind that it would go clean through a fog, but that was quite impossible. It was not like an engine cutting through a snow drift, which might be too thick for one engine, or even two, to get through, but by putting on three or four they might force their way right through into the clear space beyond. That could not happen at all in any homogeneous haze, but something like it might happen in exceptional cases where the haze was limited in extent, so that the weaker light might, perhaps, just get through; then a more powerful light might go through and travel on, and in that way might appear to have twice the range of the weaker light. It had struck him several times, in witnessing these experiments, that the electric light was tried under less favorable circumstances than any of the others, the only reason he could suppose being that those who were already experienced in it felt perfectly sure that, tried in any way, it would prove the most powerful light. There were smaller lenses, there was the imperfection in the long leads, and one or two other circumstances; for instance, it would have been possible to work one of the arc lights with the whole Fresnel arrangement, and there was no heat given off by the arc, though with gas or oil flames that would not be possible; but the suppression of part of the Fresnel arrangement cut off some 30 per cent. of the available light.

Messrs. Kincaird & Co., engineers, Greenock, have contracted to supply, at a cost of between £2,000 to £3,000, dock gates for the San Fernando Dock Company.

THE PRESENT ASPECT OF MILD STEEL FOR SHIPBUILDING.

By JOHN WARD.

Read before the Institute of Naval Architects.

There are few industries in our country which, through scientific skill, have undergone such marvellous changes in so few years as the professions of shipbuilding, bridge building, and boilermaking through the successful manufacture of mild steel by the process known as the Siemens-Martin. So many able members of our institution have at previous annual meetings recorded their experience of this material, and furnished data for general guidance, that it becomes a somewhat difficult matter to say anything absolutely new or fresh on the subject. The present aspect of mild steel as applied to shipbuilding is, however, specially interesting from the fact that the relative prices of steel and iron so closely approach each other that steel steamers can now be built on the Clyde as cheaply as iron ones of the same dimensions, thus giving the owner of a steel steamer the advantages of greater deadweight, and a material which is much more reliable under all conditions of the ship's life than iron. This being so, and the firm of which I am a member having had, perhaps, as large an experience in the use of this material as any of the professional members of our institution, it may neither be uninteresting nor uninstructive if I supplement the paper read before this institution by my partner, Mr. William Denny, in 1880, and put on record a general statement of the work done by us in this material up to date, of the treatment given it in working, of total losses through failures in working, and, generally, the reasons our clients and ourselves have for our faith in this material under almost all conditions of treatment.

Since eight years ago we built the Union Company of New Zealand steamer Rotomahana, the first ocean-going merchant steamer ever built in this material, we have delivered to owners eighty steel vessels, varying in gross tonnage from 50 to 5,000 tons, and aggregating upwards of 118,000 tons gross register. We have used in their construction upwards of 51,000 tons of mild steel, made up of nearly 375,000 separate pieces of plates, angles, channels, bulbs, and bulb trees. This number is made up from the order books in which lugs and other small pieces are ordered in long lengths. If the work at present on hand in the yard is added, our tonnage and total of material used would be proportionately increased. In working this material, we have for the last five years gone on the general principle that, if steel could not stand the maximum amount of rough usage it is sure to get in a shipyard in punching, shearing, hammering, furnacing, etc., the sooner it failed, and the defects made known and remedied, the better; for were special precautions necessary for working it, as many people still believe, so surely would this necessity bring about its certain failure and rejection, as no amount of instructions would ever gain it better or different treatment at the hands of the workman than iron has always had. In this view the workman would be right, as no material striving to supplant iron should need or receive special favor. The ability of steel to stand successfully all conditions of rough usage in working is an important and necessary evidence of its suitability to resist the severe local and general strains certain to come upon it when worked into the vessel's hull.

Our total failures in working Siemens-Martin steel are divisible into two periods—(1) that up to 1880 embodied in Mr. Wm. Denny's paper of that session; and (2) since 1880 till now. The failures may be summarized as follows: In the first 7,000 tons used, embracing 58,000 separate pieces of material, six plates and one angle bar failed. In the last 48,000 tons, embracing work to date, and consisting of about 350,000 pieces, seven plates and two angle bars failed. We have often lost more than four times this amount in a single iron vessel. These results under treatment such as I have named, are worthy of as much recognition by authorities interested in steel as the occasional failures receive, and go to prove that under conditions of local heating, or even blue (called in shipyards black) heat, failures in shipyards of Siemens-Martin steel are the rare exceptions and not the rule.

Local heating without subsequent annealing, is generally condemned by most authorities on steel, including Lloyd's Register. This condemnation is at variance with the practice allowed by the latter body. In private shipyards, boiler shops, and Admiralty dockyards, local heating is largely carried on. In fact, it is almost impossible to build a vessel without a considerable amount of local heating in some sections of the work—notably all the deck beams to which knees are welded, or the ends of the plates in all water-tight bulkheads, which are drawn out at the corner to admit of their fitting between the double frames. In Admiralty vessels, where the amount of water-tight joggled work is very large, it is all done under the effects of local heating. In shipyards the local heating of shell or deck plates is not usually necessary, but in boss, oxter and bridge plates it is not at all an uncommon thing, and with no apparent detrimental results.

Local heating in the construction of marine steel boilers is quite a common practice in the Clyde district, some hundreds of furnace and combustion chambers having been made by welding, and no difficulty whatever experienced with the material. Local heating by welding in this manner is found to be quite satisfactory, and even without annealing is considered an improvement over lap joints and seams of rivets, or butt straps. A more severe test of probable damage from local heating often occurs in making large steel boilers where it is almost impossible to get the plates perfectly fitted for rivetting, save by local heating and hammering close—one of the instances being where circumferential plates cross the joints of boiler fronts. Neither is it at all an uncommon occurrence the lifting of furnace crowns, which after a long voyage have, through carelessness or other cause come down. Not only are they locally heated, but severe local strains are set up owing to the lifting of the crown being done by means of a screw jack localized where the heating had taken place. Boilers used in this way seem none the worse for the treatment.

Fracture at a blue heat is known as a reality, and from the valuable tests of Mr. Barnaby some years ago, as also Mr. Stromeyer's paper recently read at the Institute of Civil Engineers, one would expect to find it of common occurrence in the shipyard. As a matter of fact this is not the case, and, so far as our experience goes, is very rare. In the eighty vessels mentioned, we have heated and bent between 35,000 and 40,000 frames and reverse frames for them, all of which have been worked during the temperatures of red to blue heat, and in almost all cases finished at a blue heat. Keel and ballast tank wing plates are flanged and worked at heats starting with red and finishing with blue heats. Boss, oxter, and bridge plates, also forward and aft plates in vessels with plate keels have often to be furnaced twice and even thrice before proper set is got. These always get a large amount of rough usage from workmen by hammering till cold, and yet with marvelously few failures. In carrying out recent experiments, the object was to test the working of ordinary steel under conditions fully equal to those involved in repairing a badly-damaged vessel, and under the before-mentioned conditions of local and blue heating, etc. Three experiments were made in our own works from ordinary steel plates taken from the stock, and dynamite and temper tender tests were made by permission of Mr. James Riley, of the Steel Company of Scotland, at their Hallside works, from ordinary ship plates of their manufacture. These dynamite tests are both exhaustive and instructive, but their severity is somewhat unnatural, and is greater than could possibly occur to a damaged steamer. The plates were only 2 feet 6 inches square, and the damage was consequently concentrated on one portion of a small area, while in the 12 to 16 feet lengths of ordinary shell plating the damage could hardly be localized to the same extent. The wonder is that plates could successfully stand such treatment, and, while the tests show the comparative results of same under conditions of cold, red and blue heats, yet the tests from actual damaged plates taken from a steel steamer and treated hot and cold are of more value as affording reliable data for guidance. It should not be forgotten that, even after the dynamite and blue heat treatment, the steel in the immediate vicinity of the dishings is still better than average iron supplied to shipyards while tests taken from portions clear of dishing, which received a considerable amount of work at this heat, are quite satisfactory in respect to strength, ductility and bending.

The record of tests made last year from four damaged shell plates and two shell butt straps taken from a steel steamer, are especially interesting, both as a testimony to Siemens-Martin steel—of which that vessel was constructed—and for the care with which they were conducted under the most careful supervision, including representatives of Lloyd's Register. I was personally present at the investigation, and am permitted to embody the results in this paper. The objects with which these tests were made was to find out what light could be thrown upon the following propositions, and to what extent they could be verified or disproved by actual experiment: 1. That great and special attention must be paid to steel ships, because the material, steel, is of such a peculiar and novel character. 2. That damaged steel plates could not be taken off and re-rolled to go back again in their places, even steel plates in a ship twelve months old, on the ground that they would be so strained that it would not be known or seen how far they had been weakened by the straining. 3. That in a steel steamer only 12 months old, the material, when it came off, must be regarded as a second-class material, and not fit to repair the ship with; or, if put back, the vessel would not be eligible to take the 100A class again. 4. That, by cutting out the rivets in steel plates, the character of steel is very materially injured. By cutting out the rivets and cutting off the heads of the rivets with a cold chisel, a great and injurious strain is brought on the plates in the immediate vicinity of the rivet holes, altering the character of the material very much.

From the detailed analysis of the tests made there is no evidence of loss of strength or of ductility in the material in proximity to the rivet holes of landings or butts more than is to be attributed to the process of punching, rivetting, etc., and no evidence of unseen injury by straining of the ship, or by fairing or rolling, either hot or cold. The means of thirty-seven pieces taken from solid parts of plates were 28.5 tons and 24.2 per cent. extension, and of thirty-four pieces taken between holes of landings and butts 28.8 tons and 20 per cent. extension. In the construction of steel vessels built to Lloyd's rules, and receiving their highest class under special survey, the option has been, and still is, allowed of rivetting with either iron or steel rivets. As Mr. Wildish in his able paper of last session puts it, "Iron rivets in steel plates is not a desirable combination." There are sound reasons against the use of iron rivets in steel steamers (especially in the shell and decks) and only one argument in their favor, that of being cheaper. Our uniform practice has been steel rivets for steel steamers, and with ordinary treble-rivitted butts and 20 per cent. heavier straps than the plates they connected, we have not (save in one of our earliest steel steamers, built in 1879) had a single complaint as to weakness in the butts in any of them. This I can confirm from personal examination of many of them in dry dock after repeated voyages, and also from appended letters from the superintendents of some of the principal companies which have built in this material. Their experience is valuable as evidence on the important points of strength, durability, corrosion, and safety.

In the face of these facts it is difficult to know where the reason has arisen for the extra rivetting in shell and stringer butts embodied in Lloyd's rules of this year—one of the results being a decided weakening of the butts and a partial neutralizing of the advantage of a thicker butt strap. If steel vessels have been showing symptoms of weakness at the butts, have they been rivetted with iron or steel rivets, and are they many in number? Steel vessels under the rules of the late Liverpool Registry (now absorbed by Lloyd's) were compelled to be rivetted with steel rivets, and a similar practice is carried out in all recent Admiralty work. This matter will doubtless receive early recognition at the hands of Lloyd's Register, and thus give steel vessels all the benefit of constructive thoroughness they are entitled to; for, apart altogether from the difference in the shearing strength of iron as against steel rivets, another and much more serious defect can be proved to result from the use of iron rivets either in steel or iron plates.

The series of tests of iron and steel rivets were most carried out by us in our works, and showed that, with no straining save that due to actual rivetting, caulking, and contraction in cooling, a large proportion of the iron rivets, on cutting out (after a fortnight's immersion in our dock), had fractures localized chiefly at the juncture of countersink and shank, where they broke; the shank and head, in the majority of cases, coming out altogether, while the steel rivets in every instance were absolutely free from fracture of any kind, and took from three to four times the number of blows to cut out that the iron ones did; and in almost every case the cutting out was only effected when the neck was cut completely through. The rivetting was done by journeymen, and differed in no way from work done in actual vessels, and the iron rivets were from those in use by three firms (besides ourselves) who are building vessels to highest class at Lloyd's. The cause of this investigation was the finding of a large number of apparently sound rivets (in so far as the ordinary method of testing could discover) showing blackened fractures when cut out of a damaged steel steamer rivetted with iron rivets. In cutting out a number of rivets apparently equally sound, in an undamaged iron steamer, a similar result was found, the fractures in these and in our own tests being, as in the steel steamer, principally at the juncture of countersink with shank.

The tests made from the plates in which the rivettings were done go to prove, as do also the tests made last year, that there is little difference in the nature of the material after punching and repeated rivettings, caulkings and cutting out of rivets as against punching only and without work upon it, and that even tests from the solid show but little superiority over either. It has been asserted that severe and injurious strains are brought on the plates in the immediate vicinity of the rivet holes through rivetting and cutting out. These tests show that either the annealing effect of a hot rivet counteracts this, or that the injury is purely imaginary. Local annealing or rimering, such as laid down by Lloyd's for garboards, sheer strakes, and stringers seem an undesirable nursing of steel at this period of its age, for if it be necessary to so specially treat the parts mentioned, it should be just as necessary in the bottoms, sides, and bilges. This, experience does not warrant, and probably the better plan would be to remove the special treatment laid down for those portions of the hull, and put as much proportionate faith in the goodness of Siemens-Martin steel as has, without question, been given to iron until now.

The effects of galvanizing steel plates and angles, for special work, and where cementing is admissible, is a subject with which we have experimented most carefully. In vessels designed for work in shallow rivers (of which we construct a good many) the lightest possible scantling and preservation of same from corrosion, are two of the points with which we have had to deal. We early adopted mild steel as the proper material for this type of construction, but the necessity for preservation of same from corrosion in foreign rivers was forced upon us at a later date. Preservation from corrosion, without deteriorating the material, was the object we had in view in carrying out our first series of galvanizing experiments on steel and iron plates. In the case of the former the results were most satisfactory, the advantages gained being the desired preservation, together with a slight increase of tensile strength without any material reduction in its ductility. In the case of the iron plates galvanizing had a weakening effect.

As the result of our experiments, galvanizing is now adopted by us throughout in all our special light draught work. In our most recent cellular bottomed steamers of large tonnage we have, to prevent the rapid corrosion which often takes place through the action of heat and bilge water, galvanized the plates of inner bottom which came under main boilers, and in a number of large paddle steamers we have galvanized everything under the boilers for the same reason. The experiments showing loss by pickling, also percentage of increase in weight etc., through galvanizing, were most carefully carried out by us at the Steel Company of Scotland's Blochairn and Hallside works, through the kind permission of Mr. Riley; while we are similarly indebted to Messrs. Beardmore for their kind permission to carry out at their Parkhead works in 1884 the tests which decided us upon the practice of galvanizing now adopted.

In conclusion, the present aspect of this material, as based on experience, is one of great encouragement both to users and makers, inasmuch as people see reason to forget, or have already forgotten, many of the fears they had at first regarding it. Our experience in eighty steel vessels launched or delivered with no special treatment or precaution different from that given to iron (save the annealing of butt straps of $\frac{8}{16}$ inch and upwards, as required in vessels classed at Lloyd's), warrants us in thus making public testimony in its favor. Basic and Bessemer mild steel for shipbuilding purposes we cannot say much about, as our experience of both has been small, but doubtless some of the members will, in the discussion on this paper, give us the benefit of their experience and the reasons for the faith they hold regarding all three processes. The whole subject is one of great and general interest to us all, and if the record of work done in Leven shipyard in this material since its adoption in 1878 is at all helpful, either in adding to the reliable data contained in the *Transactions* of this institution or of dispelling some of the fears with which this subject is often invested, then this paper will have fulfilled the purpose for which it was written.

THE EXPENSE OF RAILWAY TRANSPORT.

By LIEUT.-COL. T. F. DOWDEN, R.E., Assoc. Inst. C.E.

From "Professional Papers on Indian Engineering."

The system of special rates for freight on railways, so common in England, does not exist in India. The through rates in India are generally the sum of the local rates for each line, and these have to be so fixed as to afford a fair profit at all times. In two previous Papers, the effects of the speed of trains and of delays in working were considered, whilst the present Paper treats of the economical effect of working as a whole. In 1883 there were 10,563 miles of railway open in India; their working expenses averaged 204 rupees per day, and an average of 10.4 trains per day ran over every mile open, and the average cost accordingly was 196 rupees a train-mile. This, however, is merely an average, and does not give the cost of carriage in any particular case. The cost varies with the gauge of the railway, the gradients, the size of the engines, the amount of traffic, and the speed traveled. Railway working expenses may be divided into material and time charges, and the former vary after a certain point of speed, as the speed, and the latter vary inversely as the speed; and these charges approximate to an equality when the railway is working most economically. The decrease in cost per train-mile as the number of trains increases is large at first, but appears to approach a limit with twenty trains per day. The economy also effected by increasing the length of the trains is limited to about thirty vehicles, in the case of a given engine drawing a train up an incline of 1 in 300, at twenty miles an hour. There appears to be no advantage in increasing the load of a train, as long as there is room on the line for twenty trains per day, but beyond this point the weight of the train may be advantageously increased. If, however, this cannot be done for constructive reasons, the line may be doubled; but the saving with forty trains, in place of twenty, is small compared with the extension of traffic. The speed, however, on a double line is about double that on a single line. A speed of 29 miles an hour gives the greatest train and line capacity under the specified conditions. Steep gradients limit the capacity of goods trains, for their weight should not exceed what the engine can draw up the steepest incline at 10 miles an hour. The stations have also to be increased, and the through speed is reduced where the gradients are long and steep. The dividend depends on the number of units of traffic carried at a profit as compared with the capital cost, and is necessarily greatest for a given unit of profit when the railway is fully utilized, though the capital cost is somewhat increased in proportion to the increased traffic. The cost of the sleepers and ballast, the rails, the rolling-stock, and the staions being each represented by 1; the cost of the works up to formation-level may amount to a sum represented by from 1 to 4, according to the country traversed. The cost of the latter works is not much affected by the gauge, whereas the former groups would need an increase of 50 per cent. for broad gauge, in place of narrow. A large capacity for traffic, though not materially reducing the working expenses when it reaches twenty trains per day for a single line, by increasing the units of profit, increases the interest on the capital. The suitable rates for freight, as gathered from the tables representing the working expenses per train-mile, and interest on capital at 4 per cent, are as follows:

SINGLE LINE.

Easy country: 6.6 trains daily.

	Rupees.
Working expenses	2.340
Interest	0.700
Total	3.040

Heavy country: 6.6 trains daily.

	Rupees.
Working expenses	2 340
Interest	1.370
Total	3.710

Easy country: 20 trains daily.

	Rupees.
Working expenses	1.810
Interest	0 330
Total	2.140

Heavy country: 20 trains daily.

	Rupees.
Working expenses	1.810
Interest	0.550
Total	2 360

DOUBLE LINE.

Easy country: 80 trains daily.

	Rupees.
Working expenses	1.520
Interest	0.135
Total	1 655

Heavy country: 80 trains daily.

	Rupees.
Working expenses	1.520
Interest	0.196
Total	1.716

Comparing a broad and a narrow-gauge railway somewhat similarly situated, such as the Great Indian Peninsula and the Rajputana-Malwa Railways, with gauges of $5\frac{1}{2}$ feet and $3\frac{1}{4}$ feet respectively, it appears that the working expenses per mile open and per train-mile are less for the narrow gauge; but measured by the ton-mile, the standard unit of freight, this unit on the narrow gauge costs more, owing to the smaller capacity per train, whilst certain of the charges for working trains are approximately constant, whatever their size. The relative economy of narrow and broad-gauge railways depends on a balance between the cost of working expenses and interest on the capital expenditure. It appears that it is cheaper to adopt a $5\frac{1}{2}$-feet gauge for four trains a day, than a $3\frac{1}{4}$-feet gauge with eight trains, when the difference in capital cost does not exceed £1,500 per mile; whereas, with a traffic sufficient for only two broad-gauge trains, a narrow gauge would be cheaper, unless the difference in capital cost was only £250. The broad gauge is best suited for a heavy country. A comparison of a double line of $3\frac{1}{4}$-feet gauge, with a single line of $5\frac{1}{2}$ feet, gives the following results:

Easy country.	Capital Cost.	Capacity.	Interest per Train-mile at 4 per cent.	Working Expenses per Train-mile.	Total per Train-mile.
	£.	Tr'ns.	Rup.	Rup.	Rup.
Double line $3\frac{1}{4}$-feet gauge	9,798	80	0.135	1.16	1.295
Single line $5\frac{1}{2}$-feet gauge	6,000	20	0.330	1.81	2.140

As the carrying capacity of the broad-gauge-train is double that of the other, the freight charge per ton-mile is in the ratio of 1.07 to 1.295, or 21 per cent. more on the narrow than on the broad gauge, in spite of the gross carrying capacity of the narrow being double that of the broad. Comparing now double lines of both gauges with equal traffic, the results are:

Easy country.	Capital Cost.	Capacity. (equal,)	Interest per train mile.	Working Expenses.	Total per Train-mile.
	£.	Trains.	Rup.	Rup.	Rup.
$3\frac{1}{4}$-feet gauge.	9,798	80	0.135	1.16	1.295
$5\frac{1}{2}$-feet gauge.	10,580	40	0.292	1.70	1.992
Heavy Country.					
$3\frac{1}{4}$-feet gauge.	14,298	80	0.196	1.16	1.356
$5\frac{1}{2}$-feet gauge.	15,500	40	0.462	1.70	2.162

The ratio per ton mile is as 1.295 to 0.996, or as 1.30 to 1 in the first case; and as 1.356 to 1.081, or as 1.25 to 1 in the second case, showing an excess of of cost with the $3\frac{1}{4}$-feet gauge line of 30 per cent. where the country is easy, and and of 25 per cent. in heavy country.

REPORTS OF ENGINEERING SOCIETIES.

Engineers' Club of Philadelphia.—*Record of Regular Meeting, April 17th*, 1886.—Mr. H. W. Sanborn made some remarks on Recent Stream Gauging for the Future Water Supply of Philadelphia, describing the methods used, and why they were adopted, illustrated by numerous drawings and photographs, and the automatic recording gauge. The streams gauged were the Perkiomen Creek and tributaries in Montgomery County, the Neshaminy and tributaries and the Tohickon in Bucks County. The original intention was to gauge the minimum flow only, and for that purpose weirs were constructed on eight different streams. They were very substantially built, as they had to withstand the run of ice in the spring of the year. Heavy bed logs were placed at the level of the bed of the stream, and the superstructure built on that. They were made water-tight either by sheeting placed below the bed-log, to rock bottom, or a cement mortar wall. The crests of the weirs were generally about two feet above the beds of the streams, and were made of two-inch oak plank. Gauge boards were placed about five feet above and below the weirs, and connected, by levels, with the same. The one above indicated the depth of water on the crest. The one below was used only in case the weir was submerged by high water. The weirs varied in length from fifteen to seventy feet, according to the width of the stream. The formula used for calculating the flow over the weir was the one by Fteley & Stearns, of the American Society of Civil Engineers. Stream gauge stations were established near the weirs. Readings were taken there at the same time that they were at the weirs. When a sufficient number of readings, at various heights, were made, a "curve of flow" was plotted by a comparison of the two. Then, when the crests of the weirs were removed for the winter, the flow was found by referring the stream gauge readings to the "curve of flow."

The great fluctuation in the flow of the streams, caused by the great number of mills on them, necessitated a great many observations at the weirs to get a correct gauging. This difficulty was overcome by the use of automatic gauges. They were run by clock-work, and drew a line on a roll of paper, corresponding to the rise and fall of the stream. Two descriptions of gauges were used. One was designed chiefly by Mr. Stierle, of the U. S. Engrs. Office, Philadelphia. The minimum flows were found to be so small that the larger flows had to be determined. These had to be found by other methods, for the weirs would only carry, at the most, two feet in depth, while the water in the streams sometimes raised as high as sixteen feet. The measurements of the large flows were made mostly by the use of electric current meters. The measurements had to be made from bridges, and where none existed, in proper places, small suspension bridges were put up. One was built over the Perkiomen. at Frederick, of 120 feet span, and one over the Neshaminy, at Rush Valley, of 133 span. By means of the meter, the velocity of the water was taken at a great number of places in a line across the stream, and a close estimate of the velocity of the whole cross section determined. Stream gauges were placed near the meter stations, to be read when measurements were made, answering the same purpose as those connected with the weirs.

In some cases, large flows were measured by getting the velocity of the stream, by means of pole floats. When used, care was taken to have the length of them as near the depth of the water as possible, and they were run at as many stations across the stream, as was necessitated by the changes in the even flow of the stream. The rise and fall of the water during freshets was so sudden, and the stations, eleven in number, were so scattered—the water-sheds covering five hundred square miles—that it was impossible to get to, and make measurements of, more than one or two streams during a freshet. Then, many times, the freshets would come in the night, and nothing could be done but the taking of continuous readings of the stream gauges.

To overcome these difficulties with our small force, and get at least fair measurements of all the streams at the high point of a freshet, "maximum stream gauges" were set up on most of the streams. A place was chosen where the bed of the stream was uniform in width and slope, and two similar gauges set up. They were usually from two hundred to five hundred feet apart. They were made in the form of a box from eight to twelve feet long, and six inches square inside. One side opened as a door. They were placed on end and shielded and supported by heavy timbers imbedded in the soil or bolted to the rock bottom. Vertically though the center of the box ran a brass rod, which was graduated. A metallic float ran on the rod in such a manner that it would rise with the water, but would remain fixed on the rod, at the highest point the water reached, after it had fallen. The two gauges were connected by levels, and from the gauge readings the slope of the water was determined. From this the velocity of the stream was found by the Kutter formula. The daily flows of all the streams have been tabulated, from the commencement of the gauging in July, 1883, to January 1st, 1886, and the field is still being continued. The daily flows have also been shown graphically on sheets, with the rainfall on the water shed and the temperature annexed. The connection between the three is well shown. Rain-gauge stations were established over all the water sheds, and the data obtained from them, combined with that from previously existing gauges, which was kindly furnished us by the observers, have also been plotted graphically, showing plainly the variations of the rainfall over large areas. Three automatic rain-gauges were used to show the intensity of the storms.

Mr. E. V. d'Invilliers spoke upon the geological position, characteristic features and method of mining the ore at the Cornwall Iron Mines, Lebanon Co., Pa., illustrating his remarks with several maps and cross-sections, and a relief model of the mines and contiguous territory, constructed by Mr. A. E. Lehman.

Mr. A. E. Lehman then exhibited, and described the method of construction of, the Model of the above mine. It is built entirely of layers of cardboard, the perpendicular edges of which are brought to slope by engraving tools. It was so constructed that the accurate location of the contour lines was preserved, and they were drawn in ink on the finished surface, adding greatly to its practical value and intelligibility. Property lines, railroads and other topographical features and areas are shown in ink and color. The whole work is one of remarkable neatness.

Record of Business Meeting, May 1st, 1886. —Mr. Frederic Graff presented Notes Upon the Early History of the Employment of Water Power for Supplying the City with Water, and the Building and Rebuilding of the Dam at Fairmount.

The following paragraphs occur: The earliest official publication referring to the use of water power for the supply of Philadelphia with water, is contained in a report made by Messrs. John Davis and Frederick Graff, Dec. 18th, 1811, in pursuance of a resolution passed by Councils, Oct. 24th, 1811. After reporting upon the bad condition and inadequacy of the steam works then in use, at Chestnut street, on the Schuylkill, and at Centre Square, they considered the propriety of building new steam works on the Schuylkill at the Upper Ferry Bridge, and thereby supplying water to a reservoir to be built on "Morris' Hill," now Fairmount.

February 5th, 1819, the "Watering Committee" made a report, in which the following words occur: "The constant and great expense attending steam engines, and the vexation occasioned by repeated accidents, have always been present to the Watering Committee, who have ever thought water power should be resorted to, if practicable. The present Committee have been fully alive to the importance of the subject; and their desire of accomplishing it more and more excited by the success of the improvement of the Schuylkill, by dams and locks, which suggested the practicability of erecting a dam and water works near Fairmount."

At that time there was but little experience in building dams, except upon very small mill streams. The Committee asked for plans and estimates for a dam and the necessary lock, and such were submitted by Mr. Thomas Oakes, Messrs. Lehman and Briggs, Mr. Lewis Wernwag, who had built the bridge at Fairmount, Mr. Frederick Graff, the engineer of the works, and Mr. Ariel Cooley.

I herewith call your attention to a drawing copied from the originals, formerly in the office of the Water Department, combined on one sheet, of the sections and plans for the dam, as proposed by all the above named, except Mr. Wernwag. No material for his plan could be found at the date when the drawing was made.

All the plans, except that of Mr. Cooley, were upon the arched form, the chord line varying from 720 feet—that of Mr. Wernwag—to 1,000 feet—that of Messrs. Briggs and Lehman.

The plan proposed by Mr. Graff was for substantial framed wooden cribs, sunk through the mud in the deep water to the rock bottom, sheet piled at the back, and reinforced by rip-rap of stone in front and stone and earth at the back.

Mr. Wernwag's was somewhat similar, but without the sheet-pile, or rip-rap in front.

Mr. Oakes dam was to be formed by a planked box or open coffer dam from about low tide to the bottom of the river. This was intended to have been about 12 feet wide up and down stream, and in deep water would have been about 30 feet deep—filled with what was termed "shingle grouting." Upon this was to have been built a framed timber dam, extending about 35 feet up stream, filled with stone, and decked with plank on up and down stream faces, the whole rip-rapped with stone back and front.

Messrs. Brigg's and Lehman's plan was for a pile of earth and stone from low tide to the bottom of the river, about 30 feet deep; upon this was to have been built a framed timber dam, with a triangular section, and base of about 45 feet, filled with stone and decked back and front.

All these would have to be sunk through about 11 feet of mud in the deepest part of the river to solid rock.

Mr. Wernwag's plan contemplated putting the canal upon the east side of the river, and an extension of the present forebay of the works, which would, of course, have been very objectionable and detrimental to the purity of the water supply, on account of the traffic carried on through the forebay, to reach the canal.

After some negotiation, a contract was made with Mr. Cooley for the erection of the dam, locks for the navigation, and the forebay with its head arches for the supply of the wheels and pumps of the water works, for the sum of one hundred and fifty thousand dollars. His plan, upon which the dam was built, was as follows: The dam was all upon the rock, extending diagonally up stream, the overfall was 1,204 feet long, with a mound dam, on the east end, of 270 feet; it was made of cribs of round hemlock timber, sunk in the deep water which extended about four hundred and fifty feet in length, to the depth of 31 feet from the comb of the dam; in the deep water the cribs were 40 to 50 feet long up stream, and about 17 feet wide; in the shallow water and where they were on rock, dry at low tide, they were from 20 to 25 feet long up stream; they were filled with stone and planked on the up stream ends and top with three inch hemlock joists; the whole was backed and covered over the top surface of the dam with stone, rubble and gravel.

Mr. Cooley's first soundings were made on February 21st, 1819; the building of the dam was commenced April 19th, 1819; the last crib was sunk June 25th, 1821.

The water flowed over it for the first time July 23d, 1821. The use of the steam engines was discontinued and the whole supply pumped by the water wheels October 25th, 1822. This dam, which was very imperfectly built, mostly of small sized round hemlock logs, put together with two inch wooden treenails, became so much decayed as to be declared unsafe; and on the 2d of May, 1842, the work of its entire reconstruction, above low water mark, was commenced by day's work under a general superintendent and a wharf builder, Frederick Graff, Senior, being at the time the Chief Engineer of the Water Department. The old dam was entirely removed from low tide up, the timbers being so much decayed that they were only held in place by the stone filling. The old cribs below low tide having been constantly submerged, were sound, and therefore were allowed to remain, after being decked over with heavy white oak logs; upon this the new dam was constructed.

The whole of the new structure is of white pine, framed and bolted together with wrought iron spikes; after being carefully packed with stone, a deck of white oak was put upon it.

In 1871 efforts were made to obtain appropriations for building a stone dam, instead of that built of timber in 1872; but the sum estimated to do this was considered too high, and for that and other reasons the project was abandoned.

ENGINEERING NOTES.

Draining Machinery in the Valley of the Po.—The Valley of the Po, the most extensively and most admirably irrigated district in the world, is not less remarkable for the importance and the excellence of the drainage works executed in recent years. In less than 30 years, from 1850 to 1879, upwards of 600,000 acres of marshy land in the provinces of Venetia and Emilia alone, have been drained and transformed into rich country. The long lines of chimneys bordering the Canal Bianco belonging to steam elevating-machinery, remind one of a Lancashire district. The question of drainage has from all time occupied the attention of the population of these Adriatic districts; but, in consequence of the difficulty and more often the impossibility of drainage by natural flow, it is only since the advent of steam that the work of drainage has been thoroughly performed.

Drainage by machinery in the valley of the Po is almost entirely carried out on one uniform plan. The ground to be drained is fenced round by catch-water trenches or canals. Occasionally, when necessary to prevent infiltration, the bottom of the canal is deeply trenched and filled with clay. Within the circumscribed territory a system of drains is cut, in which the water is conducted to the lowest level at a point conveniently selected, where the elevator is erected. By the elevator the water is lifted into a canal or a river, in which it is carried off by gravitation. The elevators have to deal with variable volumes of water at variable heights; but, in general, the greater the height, the less the quantity to be lifted, so that the work to be done is in some sort constant. The heights vary generally in the ratio of 1 to 3.

Three systems of machines exclusively are employed as elevators: centrifugal pumps, turbines (*rouets*), and lifting-wheels (*roues elevatoires*). All of these machines are moved by steam-power, and they are the most economical. Piston-pumps employed to raise large quantities of water through small heights have shown not more than 35 per cent of efficiency. Centrifugal pumps are of great variety of form, differing principally in the shape of the blades. The turbine is only a centrifugal pump on a vertical axis, of which the pipes are replaced by the sides of a well. It consists essentially of a circular crown-plate on a vertical shaft, on the under-side of which the blades of a centrifugal pump are fixed. In some instances, the blades, instead of being free at their lower parts, are fixed to a circular plate having a central opening equal to that left by the crown plate. The wheel is placed low enough to be submerged at all levels of the water. It is driven by toothed gearing or by bands. The difference between the turbine (*rouet*) and the centrifugal pump, is that the passages for water are much larger in the first than in the second. Consequently the velocity of the water is less and occasions less friction, whilst the water escapes more freely. For small quantities of water, the pumps are more economical than the turbines, as the cost of construction of wells is saved. The turbines adapt themselves to great variation of level, whilst maintaining a high ratio of efficiency—about 75 per cent. Speed is, according to one system, altered by means of changes of toothed-wheel gearing to suit the various levels. According to another system, the speed is maintained constant for different levels, but the efficiency may fall as low as 60 per cent.

For this reason, in the Po valley centrifugal pumps and turbines are being gradually replaced by lifting-wheels. These wheels are arranged like undershot water-wheels, but with the reverse action that the water is raised by the wheel. Originally, the blades or floats were straight and radial, and the wheels were of low efficiency—about 30 per cent. They dashed the water about as each blade entered it; whence their Italian name of *ruote a schiaffo* (literally, slapping wheels). The blades are now inclined at about 60° to the radius, and are formed with a double curvature, so that the water is lifted without agitation or useless elevation; and by means of a sliding iron shutter the opening for access of water to the wheel is formed at the lower part only. The efficiency is increased as the difference of levels is increased, and it averages 80 per cent. The wheels manufactured by Mr. Zangilorami are constructed entirely of iron, and some of them are made as much as 39 feet in diameter. The side walls are exactly dressed with a clearance off the wheels at most of one centimetre, or $\frac{4}{10}$ inch. The minimum immersion is 20 inches for a wheel of 26 feet. The circumferential velocity is constant—about 57 inches per second —*Abstract of Institution of Civil Engineers.*

The Deepest Bore-Hole in the World.—The deepest bore-hole in the world is at Schladebach, near Kötschau station, on the railway between Corbetha and Leipzig, and has been undertaken by the Prussian Government in search for coal. The apparatus used is a diamond drill, down the hollow shaft of which water is forced, rising again to the surface outside the shaft of the drill, and inside the tube in which the drill works. By this method cores of about 50 feet in length have been obtained. The average length bored in 24 hours is from 20 to 33 feet, but under favorable circumstances as much as 180 feet has been bored in that time.

Depths of Various Bore-holes.

Name of Place.	Depth in Feet.
Domnitz, near Wettin	3,287
Probat-Jesar, Mecklenburg	3,957
Sperenberg, near Zossen	4,173
Unseburg " Stassfurt	4,242
Lieth-Elmshorn, Holstein	4,390
Schladebach	4,515

The dimensions of the bore-hole at Schladebach are as follows:

Total depth. Feet.	Depth. Feet.	Diameter. Inches.
189.6	189.6	11.0
605.7	416.1	9.0
661.8	56.1	7.3
1906.5	1244.7	4.7
2259.8	353.3	3.6
3543.4	1283.6	2.8
4069.9	526.5	1.97
4514.6	444.7	1.88

The various strata passed through are as follows:

	Feet.
Soil and sand, about	16
Clay	66
Sandstone (Bunter)	459
Anhydrite	59
Brine spring	—
Magnesian limestone (Zechstein)	144
Gypsum	36
Anhydrite	295
Marl-slate (Kupfersheifer)	3
Sandstone (Rothliegendes)	3,435

The bore-hole, which in January, 1885, had reached a depth of 4,560 feet, was commenced in June, 1880, but left after a year's work, recommenced at the end of 1882, and is still progressing. The cost up to January, 1885, was about £5,000.—*Abstracts of Institution of Civil Engineers.*

IRON AND STEEL NOTES.

The annual statistical report of the American Iron and Steel Association has just been published in pamphlet form by the Association, 231 South Fourth Street, Philadelphia. It contains complete statistics of the American iron trade for 1885 and previous years, and a brief review of the present condition of the iron industry in foreign countries. The following table shows the production of iron and steel in the United States for the years 1884 and 1885:

Products.	Net tons. (Except nails.) 1884.	1885.	Increase or decrease per cent.
Pig iron	4,589,613	4,529,869	— 1
All kinds of rolled iron, except rails.	1,931,747	1,789,711	— 7
Bessemer steel rails	1,116,621	1,074,607	— 4
Open-hearth steel rails	2,670	4,793	+80
Iron rails	25,560	14,815	—42
Kegs of iron and steel cut nails	7,581,379	6,696,815	—12
Crucible steel ingots	59,662	64,511	+ 8
Open-hearth steel ingots	131,617	149,381	+13
Bessemer steel ingots	1,540,595	1,701,762	+10
Blooms from ore, pig iron and scrap	57,005	41,700	—27

RAILWAY NOTES.

"It is understood that the Metropolitan Railway Company is the latest English line which has determined to adopt the steel sleeper, and that Messrs. Bolckow, Vaughan & Co., and a Welsh firm, are the concerns who have shared the first order for that line. It is gratifying that native steel-masters can now offer metal sleepers at prices more favorable than those of the German and Belgian makers, and of a superior quality."

Railway intercommunication between the Australian colonies is rapidly extending. It is expected that the South Australian portion of the International Railway will be completed about the end of April. Two new engines for the new line have arrived from Messrs. Dubs & Co., Glasgow. They are very powerful engines specially suited for hill traffic. The four sleeping cars were, at date of recent mail, expected to arrive shortly from America. They are de scribed as large, handsome carriages, with every accommodation for travelers overland to and from Victoria.

HIGH-SPEED ENGINES.—At the meeting of the Society of Engineers held on April 5, a paper was read on "Obscure Effects of Reciprocation in High-speed Engines," by Mr. Arthur Rigg, past president The author referred to the mathematical investigations of Mr. Charles T. Porter, as being the first to show how the reciprocating motion in a high-speed engine could be used to equalize pressure and conduce to smooth running; and to the engine, based on that principle, which excited great interest in the London exhibition of 1862. The text books of which the knowledge was assumed were Mr. C. T. Porter's book on the indicator, and the author's "Practical Treatise on the Steam Engine." The field of improvement opened out by Mr. Porter had not, however, been cultivated as might have been expected, and the majority of high speed engines were either so only in name, or if run at really high speeds were practically hammering themselves to pieces. In small engines these dynamical effects were insignificant, except at extremely high speeds, but in larger engines their importance rapidly increased. No true engineer ought to be content without discovering why one engine ran smoothly and another uneasily, or why an engine that ran well at ordinary speeds behaved badly at high speeds. Since 1872 the author has had exceptional opportunities of investigating those important questions, and gave in his paper some of the results he had arrived at. The two classes of engines investigated were the Porter-Allen engine and some designed by himself. In each case all the weights of the reciprocating parts were known, and the effects of their movements were graphically shown in diagrams, and the work of constructing those graphical diagrams was simply explained. A table of useful constants was given, and also another table summarizing the data and exhibiting in numerals the ratios and results. The table showed distinctly the great divergence in results in different engines, and from it and the graphical diagrams could be clearly seen the errors in design to be avoided. Engineers understood pretty well the necessity of having enough initial pressure, but sufficient attention had not been given to the heavy strains at the end of the stroke, arising from the momentum of the reciprocating parts Of the forces that could arrest those strains one only, that of a cushion of exhaust steam, could do so without injury. The proper changes were explained and the effects they would produce were deduced on the same principles as before, and compared with the effects of the original designs. It was thus shown how such engines could be made to run at high speeds with ease and security, and engineers were urged to apply the new diagrams to the engines in their charge, and to ascertain what changes were required, so that the working days of the engine might be passed in quietude, its life prolonged, and their own anxieties in no small measure diminished. The paper was amply illustrated by diagrams, and in the discussion which followed the challenge thrown out by Mr. Rigg to the makers of the modern class of high-speed engines was by no means responded to in the manner that had been anticipated. The representatives of such engines, who, the president observed, had been invited to hear the paper read and to take part in the discussion, were conspicuous by their absence or their silence.

A NEW ALPINE TUNNEL AND RAILWAY.—There are at present half a dozen or more projects for crossing the various chains of the Alps under consideration or proposed. Besides the several purely Swiss undertakings, the much-discussed Mont Blanc project, the proposals of Baron von Vautheleret for constructing a railway over the Great St. Bernhard, and the plan of Colonel de Bange, there are a number of different projects for tunnelling through the Simplon, by Herr Jean Meyer. Amongst the various proposals for tunnelling through the Simplon may also be mentioned that the plan of the Société Cécil, Paris. Instead of a long tunnel (19,900 metres, or $12\frac{1}{3}$ miles) at the foot of the Simplon, the company would construct a tunnel only 4,800 metres (3 miles) long, near the summit, at the elevation of 1,700 metres (5,576 feet). The approaches on both sides of the tunnel would in that case have an ascent of 1 in 10, and this rise would have to be overcome by means of a rack railway. The latest scheme for an Alpine railway is that by Herr Roman Abt, of Bünzen (canton of Aargau), who comes forward with an undertaking presenting novel features, and which is likely to attract considerable attention. Herr Abt proposes to connec Brieg, the terminus of the Simplon Railway, with Airolo, and thus provide the St. Gotthard Railway, instead of a competitor, with a new feeder. He does not intend to go with his railway beyond the Swiss frontier; on the contrary, he supplies railway communication between Upper Valais and the Val Bedretto, gives Switzerland an important strategical line, and all this he undertakes to effect at a cost much below any of the other schemes mentioned above. Herr Abt has described and illustrated his project in a pamphlet, which he has submitted to the Swiss federal council, and from which we learn that his railway will branch off at the station of Brieg, at a height of 679.5 metres (2,229 feet) above sea-level, and follow for 35 kilometres (22 miles) the course of the Rhône as far as Obergestelen. The ascent of the rise at Grengiols is to be by means of a rack railway 5 kilometres (3 miles) long, having an ascent of 45 per 1,000. The remainder of the line up the Rhône valley is by an ordinary railway, with a maximum rise of 25 per 1,000. The Rhône is crossed at Obergestelen, and the ascent of the left slope, as well as the entry into the Gerenthal, is effected by means of another rack railway, 6 kilometres ($3\frac{3}{4}$ miles) long, and having a rise of 60 per 1,000. The Alpine tunnel commences in the Gerenthal, at an elevation of 1,715 metres (5,625 feet), and passes under the Kuhbodenhorn, the length of tunnel being 6.3 kilometres (4 miles). The northern ascent of the line through the tunnel is 1 per 1,000, the southern descent 15 per 1,000. The mountains here consist of the best granite of the St.

Gotthard *massif*, so that Herr Abt assumes the usual tunnel lining may be dispensed with. From the southern tunnel entrance, 1,634 metres (5,361 feet) above sea-level, the railway passes along the left bank of the Ticino through the Val Bedretto, and reaches Airolo station at an elevation of 1,144.8 metres (3,785 feet). This portion of the line comprises two bits of rack railway, of a total length of 7.65 kilometres (4¾ miles), and with a descent of 60 per 1,000. The intervening stretch (3 kilometres, or 2 miles) is ordinary railway, with a fall of 20 per 1,000. The total length of the whole line is 61 kilometres (38 miles). The probable cost of the railway, which is to be a single line, is estimated by Herr Abt at about 23,000,000 francs (£920,000). Amongst the various advantages claimed for the new railway may be mentioned that the Western Railway of Switzerland will be brought into direct communication with Italy, the line from St. Moriz to Brieg, a cul de sac, being turned into an important national highway. The Rhone valley and Upper Valais will be opened up, and, what is of equal value, a useful feeder will be supplied for the St. Gotthard Railway, whilst the solution of the Simplon problem will be in no wise prejudiced, on the contrary, brought nearer its consummation. Finally, Switzerland will gain politically, for a railway of the utmost strategical value to her will be supplied, by means of which it would be possible to transport an army of 20,000 men from Lausanne to Airolo in twenty-four hours. The fortifications contemplated on the southern slopes of the St. Gotthard would gain additional importance, as they would be considerably strengthened by the new line.

On the Principal Methods Adopted for Insuring the Safety of Trains upon Italian Railways.—The traffic upon the Italian lines is not sufficient to require the adoption of the block system.

Trains following one another upon the same line of rails.—As a general rule a ten-minute interval is allowed between the departure of the trains. If the speed of the second train is greater than that of the first, this interval is increased to fifteen or twenty minutes A slow train must wait in a siding for a quick train to pass it unless it can reach another passing station at least fifteen minutes before the quick train is due there. On some lines, however, a luggage train is allowed to follow a passenger train at an interval of five minutes; on other lines the ten minutes interval applies to all trains. Trains, after leaving the station, are protected by signals for the prescribed times. Upon gradients of 25 per thousand or more no train is allowed to leave a station till informed by telegraph of the arrival of the preceding train at the next station. That these regulations are sufficient for insuring safety may be seen from the fact that during the ten years 1873–82, there were on the Upper Italian Railways (which have the heaviest traffic in the kingdom) only three collisions between following trains, all of which were caused by negligence. This corresponds to one collision per 55,000,000 train-kilometres. The average number of trains per day in the same direction upon this system is fifteen, and the maximum thirty-five.

Trains running in opposite directions upon a single line.—As a general rule these trains are run according to the time-tables without any special precautions. Notice of the departure of a train is telegraphed to the next station. If a train is more than a quater of an hour late the fact is notified to all stations up to that at which it ought to have arrived. When a train is so late as to render necessary an alteration in the arrangements for passing another train traveling in the opposite direction, the alteration, after being determined, is telegraphed to the other stations affected by it, and acknowledged by them, and the station-master at each place is bound to sign a register kept for the purpose, in which the alteration is noted. The engine-drivers and guards of the trains receive and sign written orders in respect of the alteration. This being the system in use, the station signals, except when the traffic is heavy, stand, as a rule, at "line clear." The system has the defect that it depends for its working entirely upon the attention of the railway servants. On some lines electric-bell signals have been adopted, and a description of several ways of working them is given in the paper.

The Westinghouse and Smith-Hardy continuous brakes have been adopted to a small extent during the last five years, but no decision has yet been come to as to their respective merits.

Special precautions are taken to prevent accidents in tunnels: when these are short their two ends are protected by signalmen, and when long they are divided into lengths by signal-boxes inside the tunnels.

Bell signals are used at level crossings where there is much traffic. There is a law that the gates are always to be closed five minutes before the arrival of a train, and when the gate-keeper has nothing but the time-table to guide him, if a train is late the gate has to be closed from five minutes before it is due till it has actually passed. This, of course, is a great annoyance to persons traveling on the road. To obviate this inconvenience two bells are placed in the gatehouse, one for up and one for down trains. These bells are in electric communication with the nearest stations, or signal-boxes, and warn the keeper of the approach of a train in either direction. Disk signals are placed 500 metres from the crossing in both directions and are set against the trains while the gate is open.

For the protection of trains upon steep gradients, a simple electric system has lately been introduced on lines with little traffic. A continuous current is established between two stations, and current-breakers are placed in each of the guard-houses between the stations, by which the men can signal to the stations. In the event of a train or a part of one running away down the incline, a signal can be sent to that effect to the nearest station. Another signal notifies that an accident has happened and that a breakdown engine is required.

Swing-Bridges.—Guards are stationed at each end of an opening bridge, and it is the duty of a guard when a train approaches the bridge to get on the engine, and pass over with it.

Stations.—Up to the last few years, even at the larger stations, very simple signals were found sufficient, and these were independent of the points, but at many of the principal stations the traffic has now outgrown the original arrangements and interlocking points and signals are being introduced.—*Abstracts of Institute of Civil Engineers.*

ORDNANCE AND NAVAL.

According to *Engineering*, the steamships Parthia and Batavia have been made much more economical by putting in triple expansion engines. The Parthia formerly burned 47 tons of coal a day of 24 hours in making 11 knots. During 1885-6 the consumption was 25 tons at the same speed. The Batavia gives still better results, reducing from 40 tons for 11 knots to 21 tons.

Such of our readers as are interested in artillery matters have probably noticed a paragraph in the London *Times*, stating that the new Krupp guns placed in the Dardanelles forts have signally failed, "some bursting, killing several gunners, and others being utterly unfit for their intended use as to range and precision." We have made inquiry, and cannot find any substantial foundation for this report. Officers remaining in Constantinople on their way back from the Bucharest trials know nothing of it. It does not appear likely that Krupp guns would suddenly be found to fail in three totally different respects, namely, in strength, range, and in accurate shooting. Probably some accident may have occurred which has given rise to this report, but the report in the above shape may be safely rejected.

On 28th inst. the steamship Talisman, which has just been built by Messrs. R. & W. Hawthorn, Leslie & Co., Hepburn, to the order of the Ocean Steamship Co., and engined by Messrs. Robert Stephenson & Co., Newcastle, had a very successful trial on the measured mile at Hartley. The dimensions of the vessel are as follows: Length, 320 ft.; breadth, 36 ft.; and depth, 27 ft. 9 in. Her engines are of the Holt's tandem design, having cylinders 27 in. and 58 in. diameter, with a stroke of 5 ft., and indicating 1265 horse-power. Steam of 80 lbs. pressure is supplied from one large double ended steel boiler, of a total weight of 75 tons, and this is fitted with Fox's patent corrugated furnaces. A mean result of 12½ knots was attained at full speed during several runs, and the engines worked most smoothly, and were easily handled.

BOOK NOTICES.

Publications Received.

Proceedings of the Institution of Civil Engineers.

Paper No. 2070, on the Theory of the Indicator and the Error in Indicator Diagrams, by Osborne Reynolds, M.A., LL.D.

Paper No. 2083, on Gas Producers, by Frederick John Rowan.

Paper No. 2091. Removal of Shoals by Propeller-Sluicing on the Columbia River, by Harry Hawgood, Assoc. M. Inst. C. E.

Paper No. 2139, the Injurious Effect of a Blue Heat on Steel and Iron, by C. E. Stromeyer, Assoc. M. Inst. C. E.

Abstracts of Papers in Foreign Transactions and Periodicals.

Cassell's National Library, vols. 1 to 15, edited by Professor Henry Morley, LL.D.

My Ten Years' Imprisonment, by Silvio Pellico.

Child Harold's Pilgrimage, by Lord Byron.

The Autobiography of Benjamin Franklin.

The Complete Angler, by Isaac Walton.

The Man of Feeling, by Henry Mackenzie.

The School for Scandal, and The Rivals, by Richard Brinsley Sheridan.

Sermons on the Card, and other Discourses, by Bishop Latimer.

Plutarch's Lives of Alexander and Cæsar.

Castle of Otranto, by Horace Walpole.

Voyages and Travels, by Sir John Maundeville.

She Stoops to Conquer, and The Good-Natured Man, by Oliver Goldsmith.

The Adventures of Baron Trenck, translated from the German, by Thomas Holcroft, Vol. I.

The Adventures of Baron Trenck, Vol II.

The Lady of the Lake, by Sir Walter Scott, Bart.

Luther's Table Talk.

A Popular History of Astronomy During the Nineteenth Century. By Agnes M. Clerke. New York: Macmillan & Co.

We venture to assert that all who feel tempted by the title of this book to begin the perusal of it will find it difficult to lay it aside without finishing it.

The authoress says of her work: "It embodies an attempt to enable the ordinary reader to follow with intelligent interest the course of modern astronomical inquiries, and to realize (so far as it can at present be realized) the full effect of the comprehensive change in the whole aspect, purposes, and methods of celestial science, introduced by the momentous discovery of spectrum analysis."

It is certainly a valuable and an attractive addition to scientific literature.

A Course on the Stresses in Bridge and Roof Trusses, Arched Ribs and Suspension Bridges. By William H. Burr, C. E. Third Edition. New York: John Wiley & Sons.

The first edition of this excellent work was published in 1880. The present edition differs in a few points for reasons thus explained by the author: Since the publication of the first edition of this book, engineering practice in iron and steel construction, especially in the department of bridge building, has made very material progress. The distribution of metal in pier structures has been considerably modified so as to produce concentrations in larger numbers; but chiefly the treatment of moving loads has experienced such a radical transformation as to bring it to a thoroughly rational basis. Hence portions of the book as originally written have been canceled, and replaced by entirely new matter so amplified and extended as to bring the work in all its details abreast of the best practice of the present day.

A Treatise on Elementary Statics.—By John Greaves, M.A. London: Macmillan & Co.

This treatise is based on the idea that the Laws of Motion form the only satisfactory basis on which the science of Statics can be built.

The author deduces the parallelogram of forces from the Newtonian definition of force and the parallelogram of velocities, and thus obtains the necessary conditions of equilibrium for any material system by means of the third law, without assuming the transmissibility or supposing the system to become rigid. From these and certain geometrical considerations follow the sufficient conditions of equilibrium of a rigid body.

The order of topics is as follows: Statics of a Single Particle. Statics of Systems of Particles. Statics of Constrained Bodies, Centers of Mass. Friction. Virtual Work. Machines.

An Appendix dealing with indefinitely small quantities has been added to enable the student who is unacquainted with the calculus to follow the methods employed in the chapters on Center of Mass, and Virtual Work.

MISCELLANEOUS.

At a recent meeting of the Paris Academy of Sciences a paper was read on "The Constitution of the Earth's Crust," by M. Faye. It is argued that the surface of the globe cools more rapidly and to greater depth under the oceans than on the continents, because heat radiates more freely through liquid than through solid bodies. And as this discrepancy has existed for millions of years, the crust of the earth must now be denser under the waters than under dry land. Hence, in the pendulum observations and other calculations made relative to the figure of the globe, no account should be taken of the attraction of the continental masses lying above sea-level, this excess of matter being compensated lower down by a corresponding diminution of density. In the same way no account should be taken of the feeble attraction of the oceans, because this also is compensated a little lower down by the greater density of the solid crust under the oceanic basins. The same conclusion is pointed at by the now completed triangulation of India, Col. Clarke remarking that it would seem that these pendulum observations have established the fact—previously indicated by the astronomical observations of latitude in India—that there exists some unknown cause, or distribution of matter, which counteracts the attraction of the visible mountain masses.

Mineral lubricating oils are often adulterated by the addition of cheap oils. The following tests by Herr P. Falke, published in the *Journal of the Society of Chemical Industry*, may serve for ascertaining their purity:—(1) Color. The oil must be perfectly clear, and as light as possible. It should not be turbid, which may be caused by the presence of water or other substances. If the oil be turbid by water, it froths on heating, whereas a turbidity produced by solid matters, such as paraffin, disappears on warming, and reappears on cooling. The characteristic feature of all mineral oils is their blue fluorescence. (2) Smell. The smell must be as little perceptible as possible, and should not increase on warming the oil. It mostly smells like petroleum. (3) Behavior on shaking with water. If three parts of oil be shaken with one part of water in a test tube, warmed, and allowed to stand in a water-bath for some time, no emulsion must appear between water and oil, but the latter should stand clear above the water, which should opalesce only very faintly, and be perfectly neutral. (4) Behavior to caustic soda. The oil should not be attacked by a caustic lye of 1.40 sp. gr., neither in the cold nor on warming. Saponification is a certain evidence of the presence of animal or vegetable fat. (5) Behavior to sulphuric acid. On mixing the oil with sulphuric acid of 1.60 sp. gr. it must not be colored brown, but yellow at the most; otherwise resins have not been carefully removed. (6) Behavior to nitric acid. On mixing oil with nitric acid of 1.45 sp. gr. a rise of temperature takes place, which should not exceed a certain limit. (7) Specific gravity. Although the specific gravity of oils suitable for lubricating purposes varies from 0.875 to 0.950, only a very small latitude—0.003 at the most—is permitted in contracts. It is invariably taken at 15° C. (8) Behavior on exposure to the air and heat. Spread in a thin layer and exposed to the air for some time, its consistency must not change, nor should it become acid on being heated continuously above 150°. Heated in open vessels it should not give off combustible vapors, except at a high temperature, which is usually specified in contracts. Its flashing point should be ascertained in Abel's apparatus. (9) Behavior at a low temperature. It should bear a low temperature without losing its lubricating power, nor should it become solid even at a very great cold, but it should rather assume the appearance of an ointment. (10) Test for consistency. This determination is most important. The velocity of efflux of pure rape-seed oil is taken as a standard, and that of the mineral oil compared with it. 100 cc. of the sample are allowed to flow out of a burette with tap, while the time which is required is noted down.

The following is suggested in the *Electrician* as a perfectly fair arc lamp carbon test:—Take a dynamo machine, with its full complement of lamps, and trim the lamps with the same make of carbons; note the speed of the dynamo carefully, and during the test measure the current at frequent intervals with an ammeter; see that all the lamps burn freely, without hissing, and yet not with arcs so long as to flame. Measure the electro-motive force around each arc with a voltmeter. Burn the lamps until all the carbons are consumed, or burn them, say, for four hours, and then measure the length of carbons consumed, and calculate the total time that they would burn, taking the average result. In testing another make of carbon pursue the same course. You will now be able to note the difference between various grades of carbons. Some carbons will be soft, and will consume so rapidly as to make them uneconomical; others will be of such high resistance that the machine will not run its full complement of lamps with good long arcs, without increasing its speed. In such a case a lamp or two could be cut out of the circuit until the arcs are normal, and this would show the degree of economy of the first carbons over the others. It is not infrequently the custom to mix several different brands of carbons on the same circuit of lamps, and then judge of the results entirely by the length of time each carbon burns. Nothing could be further from a real test. A carbon which would burn nine hours would frequently be less economical than a carbon burning eight hours; as generally the latter carbon would enable you to burn, say, two more lamps on a thirty-light circuit than the former. Calculating the rental receipts from these two lamps, it would be found that they would more than make up the difference due to more rapid consumption of the eight-hour carbons.

A new method for producing hydrogen gas been described. Superheated steam is passed through red-hot coke in a retort. The result is a mixture of hydrogen and carbonic oxide, or what is known as water gas. These gases are then passed on into a second retort, strongly heated, in which a quantity of some refractory substance, such as firebrick, is placed. At the same time jets of steam superheated to the point of dissociation are passed into the retort, the result being a mixture of carbon dioxide and a double amount of hydrogen. The carbon dioxide can be absorbed by passing through milk of lime, and thus pure hydrogen be obtained and collected in a gas holder. One ton of coke is stated to correspond to 3,200 cubic metres of gas, and the cost is given as 0.015 franc per cubic metre.

The plans and proposal of Mr. W. H. Radford, C.E., of Nottingham, for the drainage of Newhaven have been accepted. Eighteen competitive plans were sent in. The scheme retains those sewers which are in good condition, and utilises the remainder for surface water only. New well-ventilated and flushed sewers will be placed on those streets where they are required. The sewage from the town on the west of the river will be conveyed by a main outfall to a point away from the town and near the mouth of the river, where it will impound in a concrete storage tank during high tide. The sewage will then be run into the mouth of the tidal river at half ebb, so as to take advantage of the powerful seaward current, and the last remnant of the sewage will have entered the river while there is still one and a half hours of the ebb tide left to wash it far out to the sea. On the east of the river the present sewers and outfall at the mouth of the river will be utilised; but the sewage will be prevented from backing up the sewers by a tank, and the sewers will be well ventilated and flushed. Provision is made to connect this outfall at some future time with the main outfall on the west by means of a syphon under the river.

The North Metropolitan Tramways Company notifies its intention of applying to Parliament in the present session, by petition, for leave to insert in its No. 1 Bill, now pending in the House, a clause or clauses authorizing the company to use electricity as a power for moving carriages on portions of its existing or authorized tramways in West Ham, East Ham and Leyton.

The discussion session of the Manchester Association of Engineers was brought to a close, when Mr. T. L. Daltry read a paper on "Certain Motions used in Weaving." The paper was confined to a description of the various drop-box motions in use, with a narrative of the progress which had been made by different inventors, and in conclusion Mr. Daltry briefly referred to an invention he had himself recently patented. The problem of a good drop-box motion, he said, was no easy one to solve; his aim had been to devise a motion that would run at practically any speed —160 picks, for instance—and slip from one box to any other of four boxes. This, after considerable trouble, he had worked out mainly by the introduction of excentrics, and he claimed that one great merit of his invention was the narrowness of the space which it occupied, whilst with the excentric motion, however high the speed, it did not bang the boxes, but lifted and lowered them quite gently. The chair at the meeting was occupied by the president, Mr. W. H. Bailey, and a vote of thanks to Mr. Daltry, moved by Mr. Thos. Ashbury, C.E., and seconded by Mr. Jas. Walthem, brought the proceedings to a close.

From a large number of determinations of the electro-motive force of the currents yielded by zinc-copper and lead-platinum couples in various simple saline solutions, B. C. Damien—*Ann. Chim. Phys.*—finds that the electro-motive force as a rule decreases with the time the couple is immersed. In the case, however, of the zinc-copper couple in solutions of the chlorides, the electro-motive force at first slowly increases. The electro-motive force of the current yielded by zinc-copper couple in a solution of magnesium sulphate is very constant, scarcely varying 0.017 volt during twelve months, and is not appreciably affected by changes either of the strength of the solution or of temperature. By introducing an exterior resistance of 20.000 ohms, the current becomes practically invariable, even when the couple is kept in circuit. The author proposes to employ this couple for the generation of currents of standard strength. The zinc-copper couple yields currents whose electro-motive force is almost identical for members of any class of salts containing a given acid, but varies greatly with a change of acid. Amalgamation of the zinc slightly increases the electro-motive force at first, but it decreases more rapidly than is the case when unamalgamated zinc is employed. The current obtained from a platinum and amalgamated zinc couple in dilute sulphuric acid has its maximum electro-motive force when its solution contains 30 per cent. of acid.